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Notes and Comments

Chlorella

Green slime from a stagnant pond may hold the answer to coronary thrombosis. It may also help to produce better antibiotics.

This green matter is composed mainly of Chlorella, a very simple micro-organism which is easy to grow in the laboratory. It produces a range of vital substances very similar to those built up in the human body.

Scientists are using Chlorella to make these complex organic materials for use in research. Their molecules are intricate patterns of carbon hydrogen and oxygen atoms. To distinguish them from similar substances in the body and study what happens to them during life processes, they must be 'marked' in some way.

But how can one 'mark' a chemical? Only by making some of its atoms radioactive, which means that their movements can be traced anywhere because of the easily-detected tell-tale radiation they emit.

The atoms selected for this are carbon atoms, which are the essential ingredients of all organic chemicals.

The molecules of these life substances are very complicated and may contain many carbon atoms. And it has been found very difficult, by ordinary chemical methods, to replace more than one of these atoms by a radioactive carbon atom. If there are ten atoms of carbon in one of these molecules, the end-product will obviously be much less radioactive for a given amount than if all its carbon atoms were carbon-14.

Such weakly-marked products are difficult to trace and, when they are destroyed during body processes, only the fraction containing the radioactive atom will be traceable.

Scientists at the U.K. Atomic Energy Authority's Radiochemical Centre at Amersham have a solution to the problem. They grow Chlorella under closely-controlled sterile conditions in an atmosphere of radioactive carbon dioxide. The Chlorella has no other source of carbon than the radioactive gas and all the carbon atoms of all the organic substances it evolves will be radioactive ones.

The growing of a £5000 batch of radioactive Chlorella takes one or two weeks. But the separation of the individual organic compounds it contains requires two or three months.

Demand for these from all over the world is so great that they are on order well ahead. Amersham is striving to simplify the growing process and turn it into a routine laboratory job that does not require supervision of highly trained scientists.

Once a batch of Chlorella is grown—and a 'batch' would be about 10 c.c.—separation work begins and the first step of all is to split the rather tough skins of these micro-organisms. This used to be done by subjecting a thick 'soup' of Chlorella to intense pressure (between 2500 and 3000 lb. per sq. in.) and then allowing the soup to leak slowly through a needle valve. This was a rather inconvenient process with such small amounts. Now, ultra-sounds do the job.

Centrifuging and freeze-drying of the product follow. The latter process is used because the chemicals would be destroyed by heat.

Final separation is achieved by paper chromatography, yet another scientific marvel. It is as simple as dropping a spot of ink on blotting paper. A line of the material to be separated is drawn on porous paper one end of which is placed in a solvent. The different substances in the material travel through the paper with the solvent at different rates and can be separated simply by cutting the corresponding strips of paper. The exact position of each line of pure organic compound is determined by exposing a film to the paper. The radioactivity from the compounds will blacken the film and make it simple to map their contours.

When the different strips have been cut out, the pure products are washed off into the final solvent.

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When the different strips have been cut out, the pure products are washed off into the final solvent.

But what has all this to do with thrombosis, or penicillin? Well, some heart specialists believe a major cause of the disease to be the use of large quantities of saturated fatty acids—beef, pork and mutton fats, for instance—in human diet. They think that if such fats could be replaced by unsaturated fatty acids such as maize oil or peanut oil, there would be less heart trouble. Chlorella produces a range of such unsaturated acids which can be marked radioactively and used to explore this theory.

Anti-biotic research is also benefiting because a number of amino-acids are available from the radioactive Chlorella farm. These substances are some of the bricks with which the immensely complex protein molecules are built. But poisons produced by microbes are proteins. So are the substances which the human body produces to defend itself—the anti-toxins. The use of these labelled amino-acids can thus help the physiologists to find out just what a microbe does and the best way of killing it.

Atom

Shots in the Dark

A recently-developed camera, called the evaporograph, can take pictures of the proverbial black cat sitting on a pile of coal on a moonless night. This camera needs no light whatsoever in order to take pictures. It makes its photographs by gathering the heat radiation given out by the objects upon which it is focused.

The evaporograph focuses these radiations on a thin oil film. This causes oil molecules to evaporate to a varying degree, in accordance with the temperatures on different parts of the film. By this method, the camera makes a colour image of the object photographed.

The camera which takes microscopic pictures has been developed by the U.S. National Bureau of Standards for film resolution studies. It will be used to establish new standards for measuring the resolving power of photographic films, plates and papers.

It is said to be capable of projecting parallel lines patterns as fine as 50,000 lines per inch, and the ability of photographic film to record the lines distinctly is taken as a measure of its ability to render fine detail in pictures.

In actual practice, a Bureau spokesman has said,

'the films to be measured will not come close to resolving the finest patterns which can be produced by the apparatus. However', he added, 'the equipment must be able to out-perform the materials to be tested in order that any limitations determined will be those of the materials rather than of the equipment.'

Science Horizons

Science in India and Pakistan

The forty-eighth Indian Science Congress, which was held in Roorkee from Tuesday, January 3, until Sunday, January 8, 1961, was attended by a considerable number of scientists and students; indeed, at the inaugural meeting it was claimed that some 2000 persons were present. As always, the foreign delegates were warmly welcomed and the meetings were enjoyed by representatives from Canada, Great Britain, U.S.A., U.S.S.R., Germany and most of the Scientific Attachés from Delhi.

The meetings were held in the new buildings of the rapidly rising University of Roorkee. Here on a pleasant campus with a splendid view of the snow-capped Himalayas, the members worked in thirteen Sections. It says much for the organisation

that the presidential addresses and abstracts of some fourteen hundred papers were available for the delegates, though such lavishness of print probably discouraged attendances at some meetings where the papers were read formally. Chemistry, with nearly 350 papers was the most overloaded, with Botany as a very close second.

Professor R. N. Dhar presided over the Conference with much wit and skill. His own Presidential Address was devoted to the 'Nitrogen Problem' and dealt with the great difficulty of nitrogen fertilisation in the tropical countries. He was outspoken on the deeds and misdeeds of Indian agriculturalists and emphasised the urgency of international co-operation in field experimentation. In general Professor Dhar's thesis was that national regeneration could and should take place 'through science with hard labour, great fortitude, devotion and sacrifice'.

Other presidential addresses of special importance to the British visitors were those of Dr. Hazra, of the Section of Medical and Veterinary Sciences, who discussed the progress of medicine and emphasised the continuance of the English language in teaching and in the text-books; Dr. Mallick (Lecturer in Physiology) gave an interesting address on the physiological efficiency of animals in the tropics. In the Section of Zoology and Entomology Dr. S. P. Ray-Chandhuri dealt with ionising radiations and the induction of chromosome mutations in the germ cells.

Apart from the Sectional meetings several public lectures were given. Dr. H. Shapley (U.S.A.) 'Evolution from H-atom to Man'; Dr. Farquharson (Toronto) on 'Steroid Therapy' and W. E. Swinton (Great Britain) on 'Science and the Future', were some of the special evening lecturers. A reception and dinner, and several excursions gave opportunities for delegates to meet and to enjoy the wonderful location of the Congress.

The Pakistan Association for the Advancement of Science met in Dacca in East Pakistan from January 11 to 16, 1961. This city is the scene of great activity, and new roads, splendid business and public buildings formed a background for another week of intensive discussion. The President of the Association was Professor Abdul Salam, F.R.S., of The Imperial College of Science and Technology, London. His address on 'Technology and Pakistan's attack on Poverty' has appeared in the May, 1961, issue of *The Advancement of Science*.

Once again there were a number of distinguished foreigners. Sir John Cockcroft and Sir Harry Melville represented British science and both gave public lectures to large audiences.

The Association has a rather more compact arrangement than the Indian Science Congress and has eight Sections, medicine and veterinary science being again included. The days were given to sectional meetings with considerable programmes, and each evening there was a public lecture. Even on the Sunday there were sectional programmes, though the Monday included a memorable river cruise to Jute mills.

The British Association's representative replied to the toast of the guests at the dinner held in the open air on the Saturday evening, and a few weeks later addressed a meeting of the Pakistan Association at Lahore University in West Pakistan.

In both India and Pakistan one became quickly aware of the appreciation of science and of the stirrings of progress in housing and city planning but nowhere are the local authorities unaware of the great problems that confront nations with too great populations. Criticisms of and outspoken statements on national trends were made at both Meetings—a healthy and helpful sign.

Both countries have need of sincere friends, and a scientific traveller cannot fail to be impressed by the warmth of his reception and the generosity of many new friends. He will also be impressed by the understanding and efficiency of the British Council, whose strenuous efforts to make books available to the students is an investment in goodwill that is too little appreciated in Great Britain. Books in quantity, cheap books on scientific subjects at all levels, are an urgent necessity for the development of these two great nations.

W. E. S.

African Horse Sickness

In 1960 the countries stretching from Turkey to India lost between two hundred and three hundred thousand horses and mules from African horse sickness, a figure which is 50 per cent higher than the estimate of losses made in October 1960. The disease was probably introduced to the Near East Region via the Persian Gulf early in 1959 and was probably carried by nomad herds into Iran,

Afghanistan and Pakistan where it flared up in the autumn of that year. The diagnosis was confirmed by the Onderstepoort Veterinary Laboratory in South Africa. In 1960 it was reported in India and then swept rapidly northwards and westwards to Iraq, Turkey, Syria, Cyprus, Lebanon and Jordan.

FAO has helped the countries infected to organise control of the disease, notably in arranging for supplies of vaccine from South Africa and in assisting such countries to set up their own vaccine production units in collaboration with the Onderstepoort Laboratory. Already the Middle Eastern and Asian countries have brought up their vaccine production to 200,000 doses a month—120,000 in Teheran, 50,000 in Cairo, 10,000 in Turkey and 20,000 in India. Pakistan, Afghanistan and Iraq will start vaccine production soon.

As it is not feasible to vaccinate all the thirteen million horses and mules in the infected areas, the representatives of the thirty-six countries attending a recent emergency meeting in Paris agreed on measures of international co-operation needed to put into effect the basic sanitary policies to prevent further spread of the disease. It was agreed that FAO should endeavour to organise mass vaccination immediately in those countries on the fringe of the infected zone, thus forming a 'cordon sanitaire'. This means that Turkey, Greece, Bulgaria, India and Eastern Pakistan will act as 'buffers' against the disease to prevent further spread in Europe and the Far East.

FAO

Solid State Radio Receiver

A radio receiver with six small silicon wafers as its main working parts has been developed by Westinghouse Electric Corporation of Dayton, Ohio. A solid state device, it is an experimental model designed to test the feasibility of advanced electronic systems in which the entire system function is performed within a single block of material. The wafers, no bigger than a shilling and only a quarter as thick, are joined into a single unit which performs the function of the tubes, transistors and electronic circuits of a standard radio receiver.

Science Horizons

The Proper Use of English

According to an investigation sponsored by UNESCO, English is the language most frequently used for scientific publications.

A recent communication from Dr. G. de Wind and J. B. A. Nijssen, of the Central Laboratory, T.N.O., Delft, urges that British scientists attending conferences abroad should bear in mind the need for care in their choice of words and for clarity of expression and articulation. Indistinct and colloquial use of English is an unnecessary barrier to communication and one which could surely be removed with little effort and with a great gain in mutual understanding and regard.

Television and X-rays in Surgery

A television unit that may revolutionise the use of X-rays in medicine and especially in surgery has been developed by Australian scientists working in Melbourne.

The unit, known as Vistodax, used with an X-ray machine, stores the momentary X-ray image and displays it for a prolonged period on a television screen so that the surgeon can study it as he operates. Normally, a doctor calling for an X-ray during an operation may have to wait ten minutes for it to be developed. Sometimes several X-ray photos are needed, in bone surgery for instance, and this may lead to long delays and a protracted period of anaesthesia. With a Vistodax unit, these delays are avoided; and the process offers the added advantage of producing a much clearer image while at the same time vastly reducing the radiation hazard.

Vistodax is operated from outside the theatre by a technician who receives instructions by intercommunicating microphone. Images can be projected simultaneously on to several TV screens in other parts of the hospital, enabling the surgeon to obtain advice from experts outside the theatre during a critical stage in the operation, and making it possible for medical students to watch the operation in all its phases.

Unesco

Control of Agricultural Pests

Methods of using isotopes and radiation sources in agricultural entomology were discussed by experts from eleven countries at a recent symposium

held by the International Atomic Energy Agency in Bombay.

Among other interesting techniques described at the symposium were those of using insects against themselves, as for instance, the release among insect populations of male insects made sterile by radiation. This, it was pointed out, had already been tried successfully in some cases. For example, screw-worm flies in the Island of Curaçao were completely eradicated in 1954 by four months of sterile male release. Male screw-worm flies, irradiated as pupae in the laboratory, were released in nature, and since the female insects of this species mate only once, there was no reproduction by those which mated with the sterile males. A similar programme was launched early in 1958 in the south-east of the United States, and towards the end of that year more than 25 million sterile males were being released each week from aircraft over 80,000 square miles in Florida, Georgia and Alabama. The operations were so successful that no native screw-worms were found after February 1959.

Possibilities of wider application of this technique were discussed at the Bombay symposium, especially to such pests as the Mexican and Mediterranean fruit fly and the tsetse fly. It was, however, pointed out that while this technique appeared very promising, even better results could perhaps be expected from radiation-induced genetic changes which would eliminate an insect population in a few generations. It was also suggested that in some cases these techniques might be employed in combination with the use of insecticides.

The use of radioisotopes in the study of the biological and ecological characteristics of insects was considered at a separate session of the meeting. Thorough knowledge of life history, migration habits, feeding behaviour and other characteristics of insects is essential for all research on insect pest control and for the development of effective control measures. It was emphasised that large-scale ecological studies should first be carried out in detail; otherwise, the results of newly developed chemicals and radiation control might indeed be very poor.

Bulletin of the International Atomic Energy Agency

Sun Pools

Many tropical countries are poor because they lack the basic resources necessary to produce power—coal, oil, and swift-flowing rivers. But there is one resource of which tropical countries have plenty. That is sunlight.

I shall always remember the remark of a French scientist in Africa, while we were being grilled under a cloudless sky. He pointed to the sun and said, 'That's our nuclear reactor'.

He was, in scientific fact, right. The sun is a thermonuclear reactor, 864,000 miles in diameter. It produces nuclear energy, and the radiations on which all life on earth depends, by building up hydrogen atoms into helium and releasing, thereby, energy a thousand times greater than that which is obtained from splitting atoms. We have imitated this process on earth but only in the cataclysmic explosion of a hydrogen bomb. This artificial process is possible because in the explosion of the atomic- or fission-bomb which is used as the detonator, heat equal to that of the heart of the sun is produced. It is produced only for an instant —but long enough to 'weld' the hydrogen atoms. Hopes of controlled fusion are at the moment deferred, though encouraging results have been obtained recently in America.

But why bother about artificial processes, when we can get our fusion-energy free from the sun? The answer is that, while we get plenty of it, it is diffused and, though plants can use it to convert elements into the food we eat, by a process known as photosynthesis, we have managed, so far, to exploit it only as heat.

The energy of the sun's rays is scattered—which is a good thing for us since we could not survive the radiation—but to reconcentrate it as a strong source of power is difficult. French scientists, in the Pyrenees and in Algiers, have exploited huge concave mirrors to concentrate the sun's rays to produce intense heat for metal smelting and other purposes. The U.S.S.R. has extensive solar energy schemes in areas remote from other sources of power. And in Israel, Dr. Henry Tabor of the National Physical Laboratory has produced an ingenious 'black surface' system.

One of the troubles with the solar mirror methods is that heat is lost by upward convection. Dr. Tabor overcame this by placing above the

curved mirror, a blackened surface (black absorbs heat) on which the rays concentrated. A system of pipes was installed behind the black surface in which water could be converted to steam. This 'solar engine' is being adopted commercially in a factory at Beersheba, in the Negev desert.

To capture enough sun, however, to provide energy on a scale big enough to run a power-plant would require several square kilometres of expensive mirrors. Twelve years ago, another Israeli scientist, Dr. Rudolf Bloch, of the Dead Sea Potash Company, thought of a way in which, instead of using square kilometres of mirrors to produce solar energy, square kilometres of *water* could be used—and salt water at that. In a hot water cistern the hot water rises to the top and the cold water stays at the bottom. Unless they are stirred, they do not mix because cold water is denser than hot. What Dr. Tabor's 'sun-pool' does is the reverse. Using very salt water for the bottom layer, and fresh, or not-so-salt, water for the top, it ensures that the layers will not mix—because, in this case, the salt makes the bottom layer denser. Furthermore, if the bottom of the pond is black, it will attract the heat and the bottom waters will get hotter and hotter. This heat cannot evaporate because of the insulating layer of less-salt water between it and the surface. In experiments carried out near the Dead Sea, it was found that while the water at the top was merely tepid, the salt-water two or three feet down could easily scald the skin of one's hand. In a shallow pond a square kilometre in extent, the heat generated in this way could be converted into electricity. It is believed that the capacity of such a plant would be great and that the price per unit of electricity would compare favourably with present estimates of the cost of producing electricity from the atomic power plants now being built in this country.

Ritchie Calder, UNESCO

Iodine-132

It is not often that a customer orders one thing, but gets another and says nothing. Yet every day, the Radiochemical Centre of the U.K. Atomic Energy Authority at Amersham receives orders for a substance called iodine-132 but sends off a completely different chemical element—tellurium-132

The reason is that iodine-132 is a radioactive material which disintegrates, or decomposes, very rapidly. In fact, it takes only two hours and twenty minutes for half of any amount of this material to disappear (its 'half-life' is 2·3 hours, in scientific terms). This does not give anything like enough time to get a consignment to a hospital or a research centre. Therefore, some other radioactive substance must be used which, on disintegrating, gives iodine-132.

Tellurium-132 is this substance. It has a half-life of a little over three days. It is sent in an easily handled form packed in a glass tube and the customer has only to pour a predetermined amount of a weak solution of ammonia through the tube to obtain the corresponding quantity of iodine-132 which has been forming while the tellurium-132 is in transit. The tube can be repeatedly 'milked' for iodine.

The reason for using such a short-lived material is that most of its applications are in studies on thyroid disorders or the treatment thereof. The thyroid has an exceptional faculty for accumulating iodine.

The tellurium is obtained by subjecting uranium metal wire to an intense flux of neutrons in the BEPO reactor at Harwell. A certain proportion of the uranium atoms it contains are split by the neutrons and produce tellurium-132 as one of the fission products.

At Amersham, this wire is processed by remote control to extract the tellurium and prepare it for despatch.

Atom

THE DEVELOPMENT OF SCIENCE AND TECHNOLOGY IN THE FUTURE*

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Science and technology are today advancing more rapidly than at any time in history, and the pace of advance is accelerating rather than retarding. This is due in part to the developments of technology which provide ever more powerful tools for the scientists. Whilst I was at school I used to read the small popular science books describing J. J. Thomson's experiments which led to the discovery of the mass and charge of the electron, and of the delightful experiments of Millikan in which an oil drop was made to move up and down suspended in an electric field, its motion depending on how many electrical charges it had, so that the electric charge could be measured. I was also at school when Rutherford (Fig. 1) discovered the structure of the atom—the central nucleus carrying a positive charge surrounded by electrons.

All of this experimental work was carried out with extremely simple and primitive apparatus usually made with the hands of the experimenter. One of Rutherford's experiments demonstrated that nuclei of nitrogen atoms could be transmuted into oxygen atoms by the impact of high speed helium nuclei ejected from radium. With these atomic projectiles it was possible to transmute a number of the light elements but the number of transmutations observed got fewer and fewer with increasing atomic weight and nuclear charge of the element bombarded since the large nuclear charge repells the approaching projectile very powerfully. So it became clear to Rutherford that more powerful atomic artillery was required. I was fortunate to be a young research worker in the laboratory

Fig. 1.—E. Rutherford, F.R.S.

with training in electrical engineering and mathematical physics, able to take up this challenge.

My knowledge of German was just good enough to read a paper by a young Russian physicist, Gamow, which suggested that hydrogen projectiles speeded up by a few hundred thousand volts would be more effective than helium projectiles in penetrating the powerful electrical defences of atomic nuclei. Fig. 2 shows the apparatus Dr.

* Radford Mather Lecture delivered at Coventry on February 10, 1961, at a meeting arranged by the West Midlands Area Committee of the British Association.

Fig. 2.—Acceleration of atoms, Cavendish Laboratory, 1932. (*Copyright Keystone Press Agency Ltd.*)

Walton and I built during the next three years—the main parts of it largely with our own hands, but we made use of large diameter glass cylinders used at that time for petrol pumps. With this equipment we were able to transmute many of the light elements, lithium first, then boron, then beryllium, then carbon, nitrogen, oxygen and so on. We were able to add to our armoury of projectiles by the discovery by an American chemist, Urey, that a second form of hydrogen existed of about twice the atomic weight of ordinary hydrogen. Urey separated a few precious cubic centimetres of the heavy hydrogen from ordinary water by electrolysis and sent a few cubic millimetres to Rutherford. When this was used as a projectile to bombard heavy hydrogen targets it was found that enormous numbers of neutrons were produced, the elementary particles which had been found by Chadwick in our laboratory a year earlier.

These neutrons in turn were used as powerful new tools and they proved to be especially potent in penetrating the barriers of heavy atomic nuclei. They were used particularly to produce radioactive forms of most of the elements—the so-called radio isotopes, which in turn have become powerful tools of science, particularly biology. Most important of all, perhaps, the study of the impact of neutrons on the heaviest element, uranium, led to the discovery of fission, and that in turn led fourteen years later to the first controlled chain reaction in Fermi's atomic pile in Chicago. From this primitive atomic pile (Fig. 3) put together with the hands of the Chicago physicists has been developed the giant nuclear power stations which are coming into commission this year at Bradwell (Fig. 4) and Berkeley, each to produce 300,000 kW. of electricity; whilst Calder Hall has been steadily producing about a billion units of electricity a year for some time. I have given this as an example of how one discovery leads to another, often in a completely different field of science. Discoveries in biochemistry following on discoveries of the neutron and artificial radioactivity.

We can be pretty certain that by the discovery of fission we have much more than doubled the world's energy reserves. We have also made a beginning in the long-term quest of developing heat and power from the opposite process of fusion together of light nuclei. This has been the source of energy of sun and stars for several billion years. This could provide energy for as long as mankind can exist (Fig. 5).

Cosmology

The work on nuclear transmutations in the 1930s had another important consequence in enabling astronomers to understand how the stars develop their energy. At first matter is gathered together by the gravitational forces of attraction and in this process is heated up very slowly until its central temperature reaches a few million degrees centigrade. At this temperature the nuclei of the gas, which are mainly hydrogen, are moving about sufficiently fast for them to begin to fuse together and through a sequence of these fusion processes helium is formed from hydrogen. The mass of the helium nucleus is less than that of its constituents. In the process of fusion together, mass is lost and converted into energy. This energy release can be calculated from Einstein's famous equation $E = MC^2$.

The energy appears in gamma radiation which

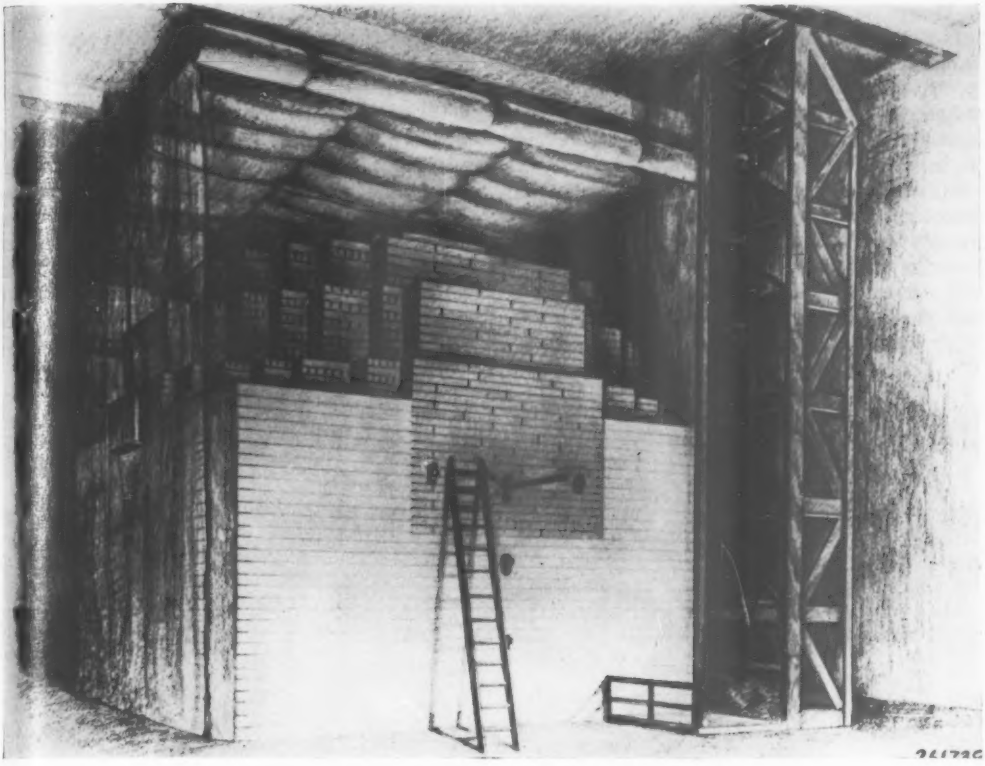


Fig. 3.—Fermi's atomic pile in Chicago. (*A.E.R.E., Harwell.*)

is emitted in the process of fission and in the energy of motion of the resulting nuclei—all of this results in heating up the star still more and the central temperature of our sun is now about 15 million degrees and the temperature is still rising. As the temperatures rise heavier elements are formed and fusions together of carbon and hydrogen, nitrogen and hydrogen provide another method of converting hydrogen to helium thus stoking up the solar furnace still more. The stars ultimately run out of their hydrogen fuel and the fusion of helium nuclei then takes up the stoking and central temperatures of several hundred million degrees can be reached. When this happens life on our planet will be pretty difficult or extinct. In the end the star either collapses to a small radius and becomes what is known as a White Dwarf or in some cases blows up and becomes a super novae in a giant nuclear explosion by comparison with which our hydrogen bombs are insignificant.

Radioastronomy

Astronomers have now got the new tools of radioastronomy to help to observe the Universe. When the Joddrell Bank telescope looks, for example, at the Crab Nebulae radiowaves are received from it showing that it is still in a state of violent electrical disturbance due to charged particles whirling around in giant orbits.

Radio waves come also from colliding galaxies far outside our own galaxy. Cygrus 'A' is one of the sources of radio waves picked up by radio astronomers: Fig. 6 shows two galaxies moving through each other.

One of the important uses of radioastronomy is to locate very distant stars. Recently a radio telescope at Cambridge and another one in California picked up a radio star and fixed its position within an accuracy of about a second of arc. They then asked the optical astronomers on Mount Palomar to look for it with their 200-in. telescope. With their ordinary optical viewing instrument it was invisible but by using an electronic device they were able to find the radio star and were able to measure the spectral distribution of its light. From the reddening of this light they found that the star was moving away from us with a speed of 90,000 miles a second, about half the speed of light. From this and their previous experience they deduced that it was so far away that the light they were seeing had started on its journey 6000 million years ago, so it lay on the boundary of the observable universe. These boundaries will be pushed back as more powerful radio telescopes are built. A 600-ft. diameter radio telescope is now being built in the United States and the University of Cambridge has plans for a more powerful radio telescope array.

One of the interests of this work is to decide between two theories of the evolution of the universe; whether it started 10 billion years or so ago in one giant genetic bang or whether matter is being continuously created and the universe is in a state of equilibrium.

Exploration of Space

The exploration of nearer regions of the universe is likely to take place with the powerful rockets able to put many tons into space which are now becoming available. The small satellites, one or two feet in diameter, have already enabled measurements to be made in the space between the earth and sun and planets. One of the most important early discoveries was of the existence of two belts of fast moving nuclei of hydrogen and electrons; the first centred at a distance of about 1000 miles and the second at a distance of 15,000 miles. These are probably particles thrown out of the sun and trapped in magnetic fields in the space outside the sun. They will provide a considerable hazard to any space travellers of the future, since they could get powerful radiation doses from these particles.

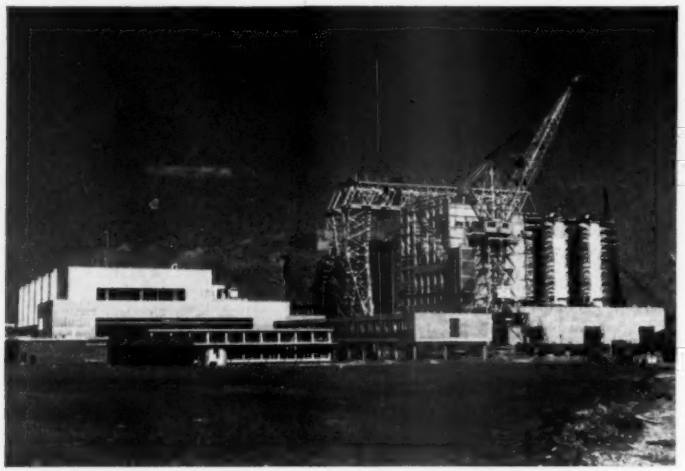


Fig. 4.—Bradwell Nuclear Power Station. (*U.K. Atomic Energy Authority.*)

British scientists are now proposing to use U.S. SCOUT Rockets to put into orbit a 20-in. diameter satellite carrying 100–150 lb. of equipment to study the properties of the upper atmosphere.

U.S. scientists are preparing to mount telescopes in satellites to enable them to take photographs of

the stars without the complications introduced by the earth's atmosphere which cuts off ultra-violet light and introduces turbulence which blurs their pictures. The first project is designed to mount an 8-in. diameter telescope and a T.V. camera to transmit the images back to earth. This telescope will have to be stabilised in space to 10 seconds of arc. Later projects scheduled for 1970 will aim at mounting a 36-in. diameter telescope. This will need to be stabilised to about 1 second of arc. All of this is a formidable job, so space research will be very expensive. For this reason increased collaboration between European countries and the United States is now being arranged.

We will have to leave the difficult and expensive projects of putting a man into space and landing him on the moon or planets, dead or alive, to the United States and Russian scientists who have billions of dollars and tens of billions of roubles to spend on such projects. The planets will be pretty inhospitable. Mercury has practically no atmosphere; Venus has a dense cloud-bound climate mainly of carbon dioxide with no free oxygen and the temperatures of the surface has recently been estimated from radioastronomy observations at 300° C. Mars has a highly rarified atmosphere which could hardly rear the warlike Martians of H. G. Wells. Jupiter is reputed to be surrounded by belts of radioactive particles ten times more dangerous than the belts round the earth. The conditions on the outer planets are even less favourable so the astronauts will have a tough time.

Properties of Materials

In my school and university days the properties of materials was a rather dull subject, being

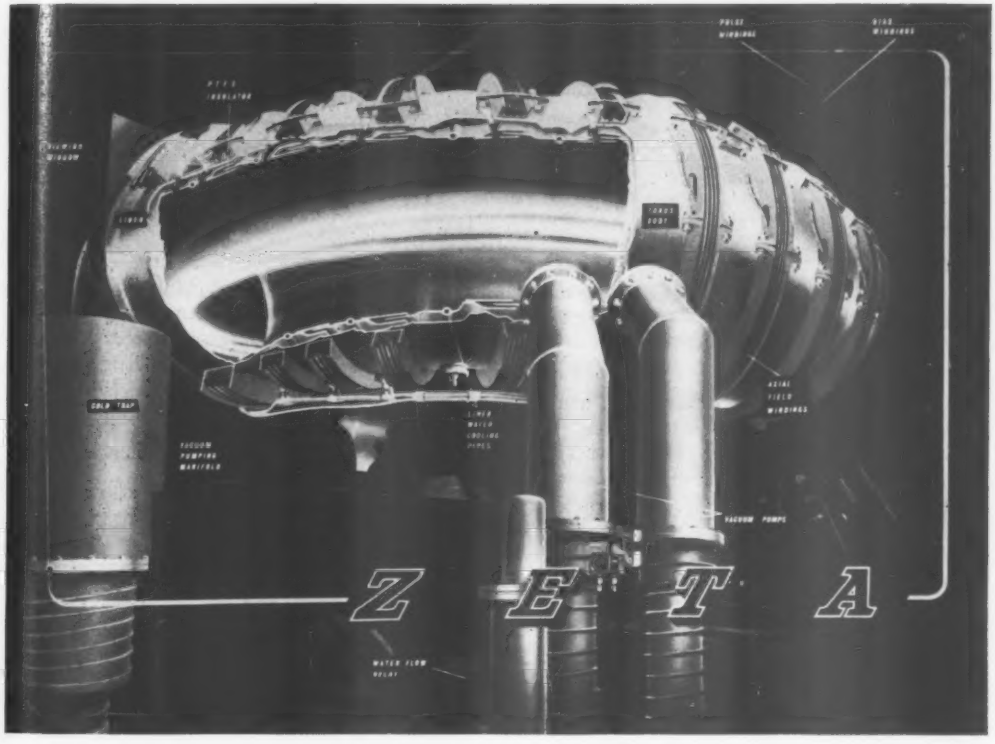


Fig. 5.—ZETA. (*A.E.R.E., Harwell.*)

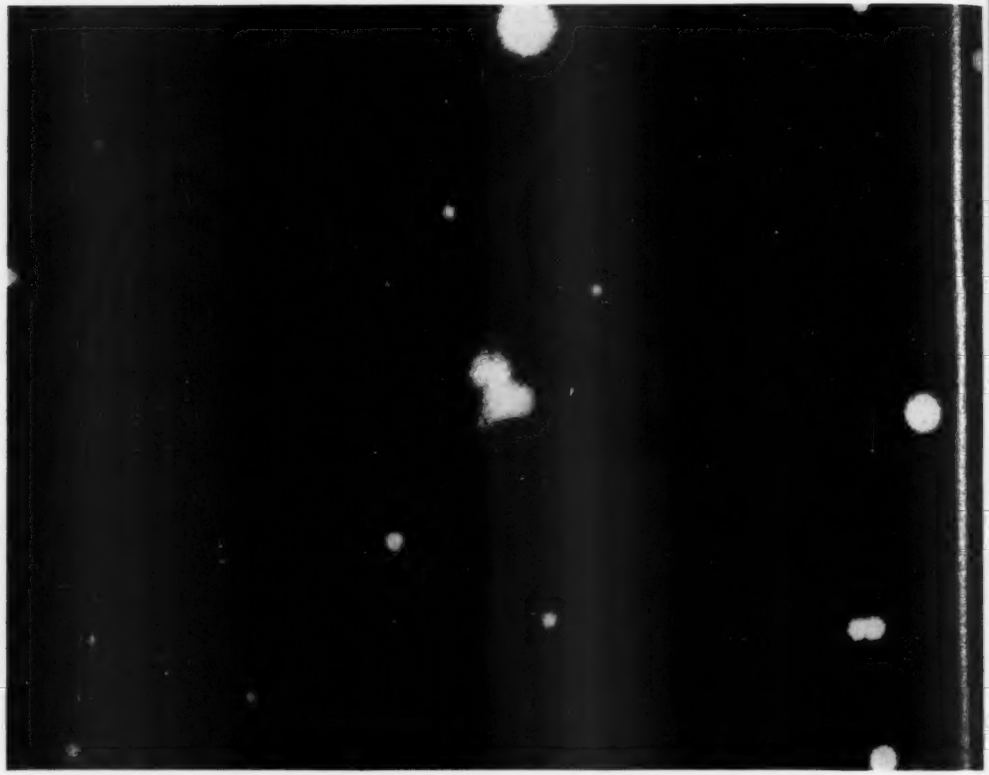


Fig. 6.—Cygnus 'A' radio source. Photograph from the Mount Wilson and Palomar Observatories. (From *The Exploration of Space by Radio*, by Professors Lovell and Brown—published by Chapman & Hall. *Photograph by permission of Jodrell Bank.*)

concerned with the overall behaviour of materials under stress and under different physical conditions. During the last twenty years, however, this subject has come alive with our growing knowledge of the internal structure of solids, the arrangement of atoms into crystals and our knowledge of the way in which electrons move about inside the crystals. With the powerful new vision of the electron and ion microscopes we can even see individual atoms inside solids and have come to understand why solids have only a fraction of the strength which on an idealised picture they should have. We are learning much more about the factors which make metals crack after being vibrated for a long time—as happened in the case of the Comet I disaster. All of this will help us to select alloys to give particular desired properties without relying on our present rather empirical methods.

Electronic Computers

Scientific research has led to the production of a new variety of solid materials known as semiconductors of electricity. These properties lie in between the metals and the insulators. By taking a material such as germanium—obtained from flue dust, or silicon, and first reducing impurities to less than one part in ten million or so and then adding a few parts in a million of a special impurity, a material is obtained from which transistors can be built to perform most of the functions of an

electronic valve. In this way transistorised hearing aids were developed and we now have transistorised radios. More important than this is the ability of transistors to switch electrical impulses in less than a millionth of a second with great reliability, so that they are now being used to construct a new generation of electronic computers which will be able to do calculations one hundred to one thousand times as fast as the computers we now have in our universities and research institutes. They will also have much more powerful memories—stored on magnetic tape or in thin magnetic foils—in which preliminary steps in the calculations are stored. These computers will greatly help the development of science for they will make possible calculations which would take far too long to be practicable using earlier computers. They can be used, for example, by astronomers to work out the life-history of stars, to calculate how the temperature of the sun will gradually rise and how the nuclear transmutation in its interior develop, and how this will affect the life-giving radiations reaching us on earth in the distant future. They are used by the so-called molecular biologists to work out the structure of the very complex molecules which control our bodily processes. The structure of the molecules is explored with X-rays which are diffracted by the electrons in the molecule into well-defined beams. So the scientist may have up to one thousand spots of different intensity on a photographic plate. From these he has to produce a three-dimensional map of the electrons in the molecule. The computer does this for him and he can then make a model showing where all the electrons are and from this he can deduce where the atoms are in a molecule. By this means Cambridge scientists recently worked out the structure of the molecule called myoglobin—the molecule which stores oxygen in muscle and provides the energy for muscular movement. Myoglobin contains 1200 heavy atoms mainly carbon, and a similar number of atoms of hydrogen.

Computers are being used to help to design nuclear power stations. The design of a complex structure such as a nuclear reactor has usually so many different possibilities that the designer would never be able to study all the possible variants without a powerful computing help. The computer can ring the changes on the variable very quickly and greatly helps the designer to choose the design which will give the best performance at lowest cost.

Computers will probably be used in a similar way to help to design ships—to take the data obtained from towing model ships in tanks and apply this to determine the best contour of a ship's hull to reduce the power required to drive it. The computer could also go on to work out the contours of the steel plates required to build the hull, thus greatly reducing the time spent.

Computers are also now being used to translate Russian into English in an experimental way. Their English is not yet very good but it is intelligible and no doubt it will improve as the computer's memory improves. Computer engineers are even introducing learning processes into the computer brain.

Small computers are now being built into large machines to help to make operations more precise and to give a better product. Thus the rolling of huge steel ingots into plates depends on the knowledge of the temperature of the ingot and on the dimensions of the ingot and other variables. All this information can be digested by the computer and turned into motions controlling the rolling process. This is just one example of the process sometimes known as Automation.

Automation

We can foresee that this development of automatic operation will go a long way in the years ahead. It will reduce greatly the amount of semi-skilled or unskilled labour required to produce a given amount of goods but it will greatly increase the number of skilled technicians required to keep the machines operating and designers to build them. So we will need to become a more skilled community than we are at the present time. Far more of our young people will have to receive better and longer training after they have left school at sixteen.

We ought to welcome this increased productivity which the machines of the future world will provide. They should release resources to enable us to produce all the things which are now in short supply. More houses and flats enabling us to clear the slums of our cities once and for all; more hospitals and more schools and colleges to provide for the enormous increased educational programme

of the future; better heating and more comfort in our homes.

We should also welcome the prospect of greater leisure and learn how to use it wisely. More time to travel and more time to explore the still remaining beauty areas of our country—more resources to preserve the beautiful heritage of the past; more time for reading; more time for creative work; more resources to produce new buildings of distinction.

Biological Research

I have been distracted by this train of thought from saying something about the future of biological research though I am far from qualified to do this. The new tools provided by modern science and technology are having just as great an influence as in the physical sciences. Radioisotopes are enabling biologists to find out in great detail how the very complex chemical factories of the human body work; how food is split up into smaller molecular units and is then reassembled into still more complex molecules such as myogloblin, which control our bodily processes.

We are beginning to know much more about the giant molecules known for short as DNA and RNA which are found in the chromosomes of cells of our bodies. These chromosomes control the replacement and development of cells in our bodies. Fig. 7 shows a model of what the biologists think DNA is like. It consists of a double-spiral containing several million atoms. Connecting the two spirals like links of a ladder are other molecules acting as cross-rungs. The sequence of the cross-rungs is believed to carry the genetic code. It provides the key information for all our characteristics in a four-letter code in a scroll over a million characters long. A single molecule out of place can lead to a gross genetic defect. One of the functions of the other molecule, RNA, seems to be to convey the information from the DNA molecule to the place in the cell where protein molecules are built up. Work in the Medical Research Council Radiobiological Unit at Harwell made it possible for the first time to see human chromosomes under a microscope. This led almost at once to the discovery that some types of severe genetic disease are due to an abnormal development of the chromosomes. Fig. 8 shows the chromosomes for a child suffering from the disease known as Mongolism—which is a great tragedy for parent and child. You will see that one of the chromosomes is triple instead of double and this is the cause.

Recently also it has been found that one variety of the blood cancer known as leukaemia is associated with abnormal chromosomes.

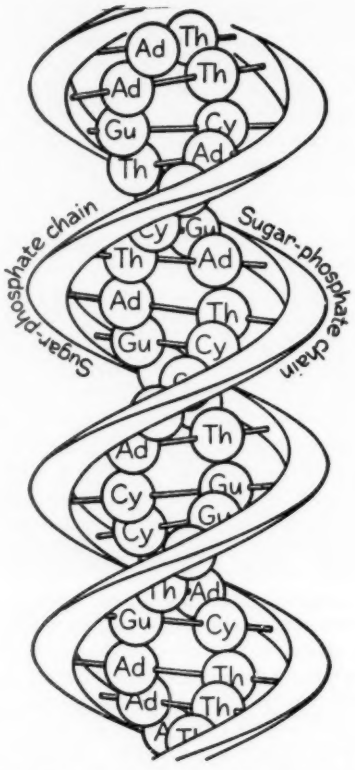


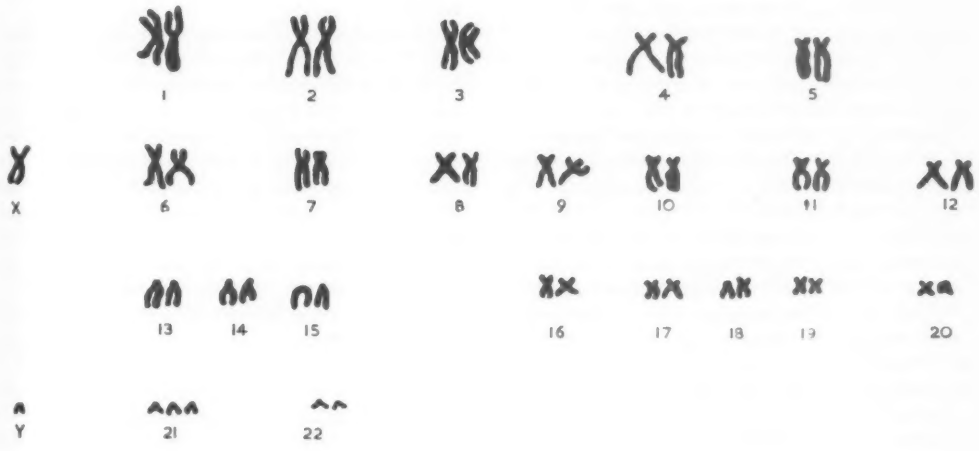
Fig. 7.—The structure of DNA according to Watson and Crick. (From *Matter, Earth and Sky*, by George Gamow—published by Macmillan & Co. Ltd. (1959). *Copyright Prentice-Hall Inc.*)

The work of the microbiologists and organic chemists in the last twenty years has produced the antibiotics such as penicillin, auriomycin, streptomycin and the sulphur drugs which have transformed medicine. But medical science has still a tremendous field of work for the future—to find methods of preventing the uncontrolled cell growth which leads to cancer and to so many human

tragedies; to overcome the degeneration of human organisms which leads to rheumatism and arthritis and other diseases which can make old age miserable.

Science and the Underdeveloped Countries

One of the major tasks of science and technology in the future is to help to increase the standard of living of the so-called underdeveloped countries, countries whose income per head is in the region of £30 per annum compared with £300 in Britain and £700 in America. This low income level results in undernourishment in many regions. According to Prof. Arthur Lewis, now Principal of the University College of the West Indies, about between one-half and one-third of the African population is undernourished. There is a tremendous body of existing scientific and technological knowledge which can be used to help to achieve economic growth if political and economic conditions can make it possible. Much indeed has been done. In West Africa great progress has been made in fifty years as farmers have developed the new crops; cocoa, cotton, peanuts, palm oil. In Latin America the Rockefeller Foundation, working in collaboration with the Mexican Ministry of Agriculture, has provided for the practical training in scientific agriculture of over five hundred young men and women from Mexico. As a result of this the Mexican corn production is now more than ample to meet all demands for corn for human food, and increasing amounts can be used for feeding animals, thus making it possible to add much-needed animal protein to the Mexican diet. The wheat harvest has also been brought to a higher level. Very important factors in this have been the improved varieties and hybrids produced through agricultural research. Without well adapted and disease-resistant varieties the increased arable area, especially that under irrigation, could not have had so immediate an effect in increasing the national agricultural product. I was in Pakistan recently and was told that scientific breeding had enabled them to increase the staple length of their cotton up to the standards of American cotton and so made it much more valuable. They can now sell



47 CHROMOSOMES XY, TRISOMIC 21.

Fig. 8.—Chromosomes of a child suffering from Mongolism.

all the cotton they can grow and their production is limited solely by water supplies. Improved methods of irrigation, leading to improved utilisation of water, could land to increased yields with great benefit to their whole economy.

Last year the great Kariba Dam in the Zambesi River was completed and will ultimately produce over 1,000 million kW. of electricity. It was hoped to use this as a great breeding ground for fish. *The Times* recently published a photograph of the lake thickly covered with a weed. This growth could greatly limit the fish population so biologists now have the task of finding a method of killing the weed. This is an excellent example of the interdependence of science and technology.

Water conservation and soil conservation are one of the major problems of many of these countries. When I visited Rhodesia last May the work of a quite small research institute had shown how to prevent the erosion of soil caused by the impact of big rain drops simply by increasing the crop cover to break the impact of the rain drops. The translation of such knowledge into practice will, however, require the services of many more trained agricultural extension workers in African countries.

Science has an important continuing role to play in combating the innumerable plant and animal pests which plague the tropical countries. The rusts which attack cereal plants; the locusts or soun flies which eat up crops; the tsetse flies which transmit sleeping sickness to man and cattle in Africa; the cocoa diseases are some examples.

The possibility of controlling sleeping sickness results from the studies of entomologists and from research in chemotherapy. Thus Zululand was recently cleared of tsetse fly at a cost of about £7 million by spraying insecticides from aeroplanes.

In countries like Greece and Italy malaria has been almost eliminated during the last ten years. But large areas of Africa are still infected by malaria and it bears most hardly on the children and 12 per cent of Africans die from malaria before they become adults. The problems of Africa are more difficult because of its size, the lack of trained personnel and the different nature of the mosquitoes.

A third major disease known as bilharzias s is caused by worms in the blood vessels and is transmitted through various species of snail which reside in rivers, and most of the African rivers are infected; so much so that it is not safe to paddle in any stream below an altitude of 6000 ft. in tropical Africa, and a large proportion of the population, white as well as black, is seriously infected. This presents a great challenge to a combined effort of medical research workers, sanatorium and hydrobiologists.

To combat these diseases and pests the experience and help of older countries will be greatly needed. In the past we established many Research Laboratories in Colonial Territories and did far more than any other country to attack these problems. With the coming of independence our help is just as much needed and we have founded an Overseas Research Council and a Tropical Research Board to organise future assistance. One of the principal ways we can help is by the seconding of scientists to work in existing research institutes overseas for periods of up to five years in the first instance. This will be a great opportunity for young scientists of the future, and I hope that amongst you are some who will take up this very much-needed and humanitarian work.

The achievement of higher standards of living in these countries depends above all on improving education at the secondary level. They need agricultural advisory workers, nurses, technicians, elementary school teachers, bookkeepers and a whole host of middle level people to deal with their developing economies. The number of children in secondary schools is in many countries only about one per cent of the age group and this needs to be increased fivefold as rapidly as possible. To help to do this Nigeria hopes to borrow about one thousand teachers a year during the next three years.

CURRENT RESEARCH ON THE CONTROL OF FRUIT PESTS

By H. L. DICKER and R. C. MUIR *East Malling Research Station.*

Materials of the crop plants' environment, i.e. carbon dioxide, nutrients, water, etc., are elaborated to form plant material by photosynthesis in the presence of light and, ultimately, through the edible crop to man. A simple food chain of this sort is illustrated in Fig. 1. But this crop also, unfortunately, provides food for man's competitors, the insect and mite pests, and these latter, in their turn, provide food for those animals which prey on them, the predators and parasites.

Man, however, is unique in this scheme in that he is able to modify the simple food chain to his own advantage by practices that come under the general heading *horticulture*. By cultivation, manuring, irrigation and so on, he can increase the flow of materials from the environment to produce a greater, or a better, crop. By breeding and selection

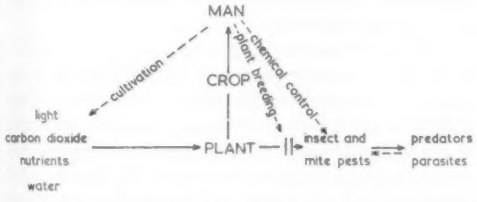


Fig. 1.—A simple food chain showing some of the means by which man may modify it to his own advantage.

he can produce plants and crops more suited to his needs. He can also reduce crop loss due to the depredations of the insect and mite competitors in a number of ways. This may be done by encouraging the natural enemies of the pests and so checking their increase; or making the physical environment hostile to the pest by applying chemicals toxic to them; or finally, we may avoid battle altogether by breeding plants unacceptable to the pest in question and thus depriving it of food.

Examples illustrating these three approaches to pest control may be taken from our present-day research in the control of apple pests.

The apple crop is the most important British fruit crop. The main features of commercial apple growing we wish to emphasise are:

(*a*) The apple tree is a perennial plant with a life of fifty years of more. Any severe check to growth suffered during the early years will almost certainly be reflected in the size of future crops. Also, heavy infestation of pests on mature trees may reduce the yield both in the current and in the following year.

(*b*) The capital cost of establishing an orchard is high. About £500 per acre is required to cover the cost of land, trees, planting, and maintenance for the first four or five years, during which period no crop is obtained. The orchard will not normally come into full cropping until it is eight to twelve years old.

(*c*) Even when cropping, the fruit has to compete in a market with the best that is imported, and this puts a premium on quality.

No one could be expected to embark on such a costly adventure were he not sure of a profitable return for his investment. Precautions necessary to ensure success will include regular control of insects, mites and fungal diseases known to cause economic injury. This is achieved at present by a rather complicated spray programme, evolved during the past four decades, which is applied annually to give protection against those pests and diseases that are known to occur most frequently.

Chemical Control of Pests

A typical, present-day programme is illustrated in Fig. 2, where arrows are used to indicate the occasions on which insecticides are applied. Aphids, apple sucker and various caterpillars appear in April and can be controlled by chemicals such as DDT and BHC or one of the organophosphorus compounds. The apple sawfly, whose larva feeds inside the young fruitlets, hatches just after the blossom period and is susceptible to BHC.

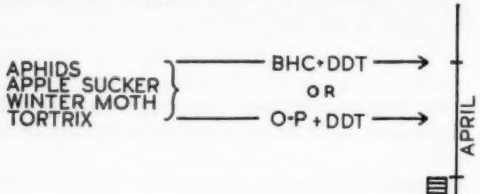


Fig. 2.—A typical spray programme against pests of apple.

Several chemicals are effective against the fruit tree red spider mite, codling moth and the fruit tree tortrix moth. In addition, from early April until late June or early July, fungicides are applied at intervals of ten to fourteen days to protect foliage and fruit against infection by apple scab and mildew.

Complete sterilisation of the orchard from all forms of insect life is neither practicable nor desirable, because apple trees are insect-pollinated, and the grower does, therefore, make every effort to conserve these pollinators by refraining from spraying with toxic substances during the blossom period.

Successful pest control by chemicals depends mainly on a sound knowledge of the biology of the pest species, effective chemicals, and efficient application. As far as machinery is concerned we rely on our sister research station, The National Institute of Agricultural Engineering, and the horticultural engineering industry. For insecticides we look in the main to the chemical industry with its tremendous resources for making and screening the very large number of compounds which have to be tested before a promising new one is discovered. If it is considered that a new chemical will be useful against a fruit pest, we begin testing it as soon as it has reached the development stage. But as horticultural scientists our main contribution is in biological research, and our chemists are, therefore, concerned more with the behaviour of the chemicals on the plant or, if you like, with *chemical ecology*, than with the development of new chemicals. In the field, toxicants under the influence of sunlight, rain and oxygen undergo weathering, or degradation to less toxic substances, losing their potency with time. The tree itself also provides physical problems such as the wettability of the leaves and their ability to retain spray deposits. As the tree grows, it adds more leaves, and these expand so that earlier spray deposits are diluted by clean uncontaminated leaf surface. Finally, the tree is a sensitive, growing organism that is easily damaged by many chemicals, thus imposing restrictions on the choice or on concentration. Consequently spray damage is a problem for investigation.

The main factors determining the most appropriate time to apply chemical control measures are firstly, the spray must be applied at a stage in the life cycle when the pest is susceptible, and secondly it must be applied before any serious injury has been caused to the host plant. Only by detailed knowledge of the habits of the species can these points be decided, and we find nowadays that lack of biological information is a greater hindrance than the availability of chemicals. Each pest species must be considered individually as these two examples will illustrate.

The apple blossom weevil comes out of hibernation in March, and practically the entire overwintering population is present on the trees before egg laying begins in the young flower buds. A contact insecticide such as DDT, applied at this

time (Dicker, 1950), will cause high mortality because weevils are very active on sunny days, and those not actually hit by the spray soon come into contact with the toxic deposit left on the branches. The habits of the adult made this a particularly easy pest to control and a single spray often resulted in extermination from entire farms; for example, not a single specimen has been observed at East Malling since control measures were applied in 1948.

Control of the codling moth, all too familiar as the larva found feeding on the seeds and core of ripening apples, has proved a much more difficult problem. From caterpillars, which spend the winter hidden underneath the bark, moths begin emerging at the end of May, and continue to do so for two months. Throughout this time eggs are being laid, and the young larvae, on hatching, quickly tunnel into the fruits where they are safely hidden from the effects of most chemicals. For success, a continuous toxic deposit has to be maintained throughout this hatching period, and studies are still in progress to discover the most effective chemical and the frequency of application necessary to achieve successful control.

Very few of the chemicals in common use exhibit marked specificity, in that they kill only the species against which the spray is directed. An example of this type is lead arsenate, which acts as a stomach poison, i.e. one which proves fatal only after it has been ingested. The great majority belong to the class termed contact insecticides, whereby mere physical contact with the spray or its deposit on the foliage, fruit or bark is often sufficient to cause death. This is an advantage when dealing with a pest, as individuals are killed before injury occurs to the host but, unfortunately, many beneficial species also succumb, and the destruction in this way of certain predators has resulted in the fruit tree red spider mite becoming a pest. When DDT is used the situation is still further aggravated because contact with this chemical stimulates the mite to lay more eggs than it would do under normal conditions.

We must, therefore, take care that in using chemicals to solve one pest problem we do not create another. As far as the red spider mite is concerned there are several acaricides available to give effective control but evidence is fast accumulating that mite populations in many parts of the world are now composed predominantly of strains resistant to one or more of these chemicals.

Thus it has become necessary to study also the effect of chemicals on components of the orchard fauna which can prey on or parasitise the pests themselves, as the indiscriminate elimination of these may lead to an upsurge of the pests once the pressure of natural control is removed. The fruit tree red spider mite is, in fact, the only one so far to exhibit this upsurge.

The Use of Natural Enemies to Control the Fruit Tree Red Spider Mite

In unsprayed orchards populations of this mite remain at a very low level due to the action of predators. There are many species, mostly belonging to the Hemiptera-Heteroptera (Collyer, 1953), but a mite of the genus *Typhlodromus* is also an important component of the predator complex (Collyer, 1958). The more common species are listed in Fig. 3, where a continuous line indicates the period of activity. It will be noted that predators are already present at the time the fruit tree red spider mite hatches from the overwintering egg in May and a succession occurs throughout the summer, covering the entire period of mite activity. These, however, are susceptible to many chemicals normally used for pest and disease control with the result that few survive in the sprayed orchard, and the mite thus increases rapidly to become a pest. It may well be that there are other pest species whose rare occurrence is due to efficient predator or parasite control, but about which we are ignorant, since our studies have necessarily been confined to those species which occur in such abundance to be rated as pests. Our present knowledge of the total orchard fauna and of the factors contributing to the scarcity or abundance of species is very fragmentary and must continue so for some time.

The simplest case for biological control is where only a single pest attacks a crop. But with apple the situation is far more complicated for, as illustrated earlier, there are several major pests, and, in addition, two fungus diseases to control. With the exception of the fruit tree red spider mite these pests have been present since the early days of fruit growing, and it was as a direct result of their depredations that chemical control measures were first introduced.

With the fruit tree red spider mite, the situation is different, for we know it can be controlled by predators. So here our present problem is to devise a spray programme which will give satisfactory control of the other pests and diseases, and yet not destroy the natural enemies of the mite.

In a field experiment, started in 1953 and continued until 1959, the interaction of the fruit tree red spider mite, *Metatetranychus ulmi* (Koch), and a mirid predator, the black-kneed capsid, *Blepharidopterus angulatus* (Fall.), was observed under four different spraying schedules.

Half the plots received a winter wash (DNOC—petroleum oil) in early March whilst this treatment was omitted from the others. Each plot was then subdivided and sprayed with a fungicide, either lime-sulphur or captan, at fortnightly intervals from early April until mid-June. The entire experimental area was also sprayed with nicotine and/or lead arsenate on certain occasions but there was no evidence that either of these chemicals affected the mite or its predator.

DNOC–petroleum oil, being ovicidal, killed many of the overwintering eggs of the fruit tree red spider mite and possibly reduced the hatch of the predator. Lime-sulphur, used to control apple scab and mildew, was also mildly toxic to the active stages of the mite and to the young, nymphal stage of the predator. Captan controlled apple scab, but not mildew, and had no effect on the mite or the predator; plots receiving this treatment could thus be regarded as controls.

The upper graphs in Fig. 4 illustrate the fluctuations in mite populations for the two most contrasting treatments, winter wash plus lime-sulphur, and captan alone. The other two treatments were intermediate in effect and will be omitted from this discussion. The mite populations are shown on a logarithmic scale as the mean number per leaf.

Throughout 1954 and the early part of 1955 more mites were present on the captan plots than on those sprayed with winter wash/lime-sulphur but, by the end of July, 1955, the position had been reversed. Early in 1956 mite populations were again highest on the captan plots, and both populations continued to increase until July, then declined rapidly to very low numbers by the end of the season. A recovery took place in 1957 and 1958, being more rapid on the winter wash/lime-sulphur plots. This trend continued during the early part of 1959 but was checked abruptly at the end of June on the captan plots and a month later on the winter wash/lime-sulphur plots.

These population changes were due to two factors. Firstly, to toxic effects of the winter wash and lime-sulphur, which resulted in lower mite populations at the beginning of each season on plots receiving this treatment. The second, and more important, factor is illustrated in the lower

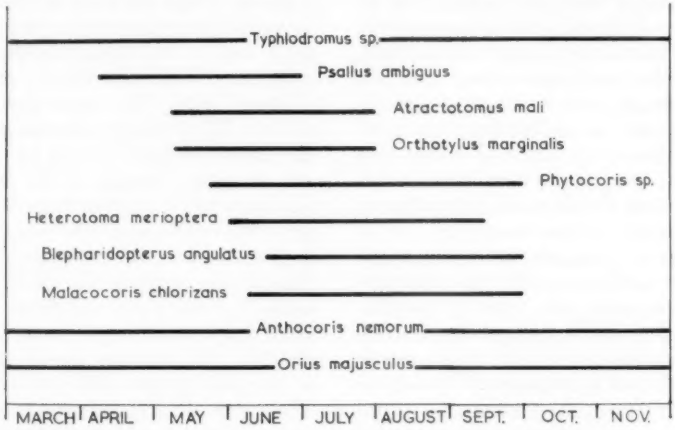


Fig. 3.—Periods of activity of the commoner predators of the fruit tree red spider mite.

graphs (Fig. 4) which represent populations of the black-kneed capsid, the only predator present in any numbers. This species steadily increased from 1954 through 1955, to 1956, when it was sufficiently abundant to bring about a collapse of the mite populations. But the mites were so drastically reduced that the predators were left with insufficient food and, although they were observed to feed on leafhoppers, this resulted in a reduced population in 1957.

With fewer predators in 1957 the pressure on the mite due to predation, was relaxed, the result being that populations again began to increase, and this trend continued throughout 1958, more especially on the winter wash/lime-sulphur plots. Increasing food supplies on these plots also led to an increase in predators which, by 1959, were numerous enough to cause another check to mite populations.

During the period 1953–9 populations of both mite and predator went through two complete cycles. On the winter wash/lime-sulphur plots the oscillations were of approximately equal magnitude in each cycle and mite populations rose to a level where foliage injury became obvious. On the captan plots the predator population remained relatively constant during the second cycle, from 1957–9, and at no time during this period were mites sufficiently numerous to cause visible injury to the trees. In each year except 1959 predator populations were lower on the winter wash/lime-sulphur plots, due to mortality caused by this treatment, and this would seem to be the explanation for the larger mite populations which were observed.

The inference to be drawn from these results is that, once established, the black-kneed capsid can prevent populations of the fruit tree red spider mite rising to a level where it becomes of economic importance, providing nothing is done to upset the balance between the predator and its prey. Such a condition was achieved on the captan plots during the period 1957–9.

This result does not, however, solve the commercial problem, because mildew was serious on the captan plots where the natural control of mites was so good. We are now searching for an alternative fungicide that will control mildew, but will not adversely influence the predator population.

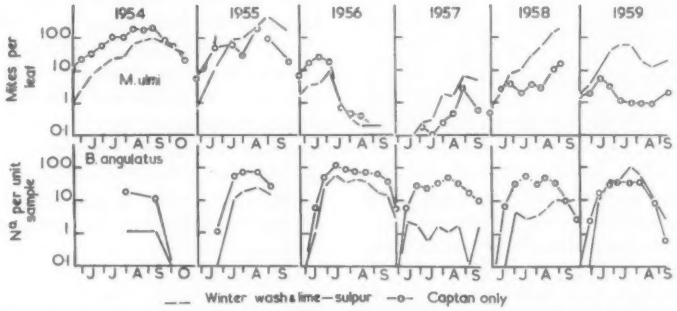


Fig. 4.—Population trends under two contrasting spray treatments of the fruit tree red spider mite, *M. ulmi* (upper graphs), and its predator the black-kneed capsid, *B. angulatus* (lower graphs).

Breeding for Resistance

The third approach to pest control, that of breeding for host resistance, is a joint effort between plant breeders and entomologists. First, a source of resistance has to be discovered, either in cultivated varieties carrying this factor or in other species. This is essentially a long-term approach to the problem of pest control as it involves the incorporation of genes for resistance with those of quality, flavour and all other factors making up a fruit acceptable to the grower and to the consumer.

One modest success, a series of apple rootstocks resistant to attack by woolly aphid, has already been achieved (Preston, 1955). The price of this success, however, was thirty years of breeding,

testing and evaluation of the performance under field conditions, before we were able to distribute rootstocks for commercial production.

TABLE 1

HOST PREFERENCE TESTS WITH STRAINS OF *Amphorophora rubi* ON CERTAIN RASPBERRY VARIETIES

Raspberry variety	*Aphid strain*		
	1	2	3
Malling Promise	×	×	×
Malling Landmark	○	×	○
Chief	○	○	×

× = susceptible; ○ = resistant.

The difficulties inherent in such an approach to pest control can be gained from our work on breeding raspberries resistant to *Amphorophora rubi* (Kalt.) (Briggs, 1959; Knight, Briggs & Keep, 1960), the aphid which transmits the more serious virus diseases of this crop. An existing variety of raspberry, Malling Landmark, on which the aphid could not breed at East Malling was provisionally selected to provide a source of resistance for further breeding. Extensive surveys, however, revealed that Malling Landmark was, in fact, colonised by the aphid in another locality in Kent. As a result of host preference tests in the insectary (Table 1) another variety, Chief, was found to be resistant to both the normal strain of the aphid (strain 1) and the newly discovered strain (strain 2). Later, a third strain appeared which was capable of colonising this variety but not Malling Landmark. Thus three strains of *Amphorophora rubi* can now be recognised, each differing in its ability to colonise various varieties of raspberry. This complicates the breeding programme since genes conferring resistance to all three strains must be incorporated in the new variety. It also demonstrates one of the hazards associated with this approach to pest control, namely, the risk that resistance may be broken by a strain already in existence, but as yet undetected, or by the appearance, through mutation, of a new strain.

Summary

Chemical control provides the quickest method of suppressing pest populations; on fruit, this has resulted in the virtual elimination from the apple orchard of many harmful species previously contributing to damage or loss of crop. Offset against this is the fact that very few of the chemicals in current use are selective, and some indeed are liable to present risks to the operators or consumers. One pest, the fruit tree red spider mite, has arisen as a result of chemical spraying, and although acaricides are available for its control, resistance to them has occurred. Thus the effective life of these compounds is limited. But on balance, in spite of its imperfections, chemical control has paid handsome dividends by leading to increased yields of better quality fruit.

The prospects of biological control are at present limited to one species, and success with this must be dependent on developing a spray programme that will control other pests and diseases, while at the same time permitting the survival of predators of the red spider mite. The possibilities of host resistance are also much to the fore. Successful application of each method, however, must depend on adequate knowledge, not only of the pest itself, but also of its relationship to others, and the environment in which it lives. A fuller knowledge of these ecological factors may permit the introduction of alternative measures for repression of pests.

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THERMOELECTRIC REFRIGERATION

By MIRIAM V. GRIFFITH *Head of Heating Research, Electrical Research Association, Leatherhead*

Any physical process, which acts so as to produce and maintain both a cooled and heated region in the same system, can be used as a refrigerator. It must, of course, be possible for the cooled part of the system to absorb heat from the material to be cooled, and for the heated part to get rid of the heat.

In 1852 Lord Kelvin suggested the principle that is used for the great majority of refrigerators, i.e. the pressure on a volume of suitable liquid is reduced so that its temperature falls below that of the material to be cooled. If the two are then placed in contact, heat flows from one to the other and boils the liquid. Its vapour is then compressed and rises in temperature. This vapour then passes to a heat exchanger where it is condensed again, giving up its heat to the air or cooling water. But long before 1852, a Frenchman, Peltier, had made some strange observations in some experiments he was carrying out on the resistance of metals. He obtained peculiar variations in temperature in the circuit, but he did not believe his results. Nevertheless, the inverse of the effect made use of in the measurement of temperature by thermocouples is called by his name, the Peltier effect. Four years after Peltier's tests were made, the scientist Lenz actually froze a drop of water in a groove between two rods of antimony and bismuth when direct current was passed through them. We think nowadays that the water of St. Petersburg must have been pretty cool already or he could not have done this with those thermoelectric materials. However, no use of the cooling effect so observed was made for a very long time and Lord Kelvin's original idea has been used up to the present day for both heat pumps and refrigerators.

Advantages of Thermoelectric Refrigerator

Although the motor-driven refrigerator is thermally efficient, a device with no moving parts would not suffer from wear and would need no lubrication. It would cause no noise or vibration. The chemical absorption unit has these advantages, but a thermoelectric refrigerator would have the additional one of not being subject to leakage.

Basic Principles of Peltier Effect

When an electric current passes across the junction between two dissimilar conductors heat is evolved or absorbed. This phenomenon is known, after its discoverer, as the Peltier effect. The rate of absorption or evolution of heat, Q, is given by

$$Q = \pi . I = I . \alpha . T \qquad \ldots (1)$$

where I is the current, π the Peltier coefficient, T the absolute temperature and α the thermoelectric power. If the direction of flow of the current across a junction is reversed, heat absorption will be changed to heat generation and vice versa. In the case of a closed circuit of two conductors, passage of a current produces a temperature difference between the junctions and the quantities of heat given out by the hot and absorbed by the cold junctions are given by

$$Q_1 = I(\alpha_1 - \alpha_2)\, T_1 \qquad \ldots (2a)$$

$$Q_2 = I(\alpha_1 - \alpha_2)\, T_2 \qquad \ldots (2b)$$

where T_1 and T_2 are the temperatures of the respective junctions.

In addition to the Peltier effect other phenomena

appear in the circuit. One of these was discovered by Lord Kelvin and is known as the Thomson effect. If a current flows along a homogeneous wire of length l, along which there is a temperature gradient, heat is absorbed or evolved at a rate q, per unit length, where

$$q = \tau . I . \frac{dT}{dl} \qquad \ldots (3)$$

τ is called the Thomson coefficient. The Thomson effect can usually be neglected as q is very small.

When a temperature difference is established between two junctions, forming a closed circuit, a small current will flow because of the Seeback effect, i.e. the potential difference developed between two junctions at different temperatures which is made use of in measurements by means of thermocouples. This will result in the consumption of an extra quantity of power Q_p where

$$Q_p = (\alpha_1 - \alpha_2) . I . (T_1 - T_2) \qquad \ldots (4)$$

where T_1 and T_2 are the temperatures of the hot and cold junctions respectively in degrees Kelvin and α_1 and α_2 are the thermoelectric powers of the two conductor materials.

When a current I flows in the circuit, Joule heat is generated at a rate W, where

$$W = I^2 r \qquad \ldots (5)$$

where r is the total electrical resistance of the thermocouple. It may be assumed that half of this heat W is absorbed at the cold junction and half at the hot junction.

Some heat will also be transferred from the hot to the cold junction by thermal conduction. This quantity is given by Q_c, where

$$Q_c = K(T_1 - T_2) \qquad \ldots (6)$$

where K is the thermal conductance of the thermocouple.

Derivation of the Performance Energy Ratio:

The coefficient of performance, C, of a thermoelectric refrigerator will be given by the ratio of the heat absorbed at the cold junctions, in appropriate units, to the power consumed, also in the same units, i.e.

$$C = \frac{(2a - \frac{1}{2}(5) - (6)}{(4) + (5)}$$

$$= \frac{(\alpha_1 - \alpha_2) . I . T_2 - \frac{1}{2} I^2 r - K(T_1 - T_2)}{I^2 r + (\alpha_1 - \alpha_2) I (T_1 - T_2)}$$

From this can be derived the optimum voltage for the thermocouples to give the highest thermal efficiency, i.e. C is a maximum where

$$\frac{\partial C}{\partial V} = 0 \quad \text{and} \quad V = Ir$$

and $$V_{\text{opt}} = (\alpha_1 - \alpha_2)(T_1 - T_2) \frac{M}{M-1} \qquad \ldots (7)$$

where $$M = [1 + \tfrac{1}{2} Z (T_1 - T_2)]^{1/2}$$

The maximum value of the C.O.P. for a refrigerator is given by

$$C_{\max} = \frac{T_2}{T_1 - T_2} \left(\frac{M - T_1/T_2}{M+1} \right) \qquad \ldots (8)$$

In these expressions, Z is defined as follows:

$$Z = (\alpha_1 - \alpha_2)^2 / K . r$$

where K and r are the thermal conductance and electrical resistance of the thermoelectric circuit. The value of Z is a measure of the quality of the thermocouple materials, and for the most efficient operation the value of $K.r$ should be a minimum. For thermoelements of equal length it can be proved that the optimum ratio of the areas of cross-section A_1 and A_2 is

$$A_1 / A_2 = \left(\frac{\rho_1 k_2}{\rho_2 k_1} \right)^{1/2}$$

and with these values of A_1 and A_2—

$$Z = \left[\frac{\alpha_1 - \alpha_2}{(k_1 \rho_2)^{1/2} + (k_2 \rho_1)^{1/2}} \right]^2 \qquad \ldots (9)$$

It is clear that for high efficiency, α needs to be high and electric resistivity and thermal conductivity low.

Expression (8) is of interest since it illustrates the departure from the Carnot cycle value of C due to the imperfections of the thermoelectric circuit.

For a refrigerator the maximum temperature drop on the cold side is given by $\frac{1}{2}ZT_2^2$. This can be about 50°C with known materials.

Metals have relatively low thermal electromotive forces, but with semi-conductors very high values are found, thus enabling reasonable values of C to be obtained. Table 1 shows some typical values.

TABLE 1

VALUES OF THERMOELECTRIC POWER, α, FOR VARIOUS METALS AND SEMICONDUCTORS

(all Related to Lead)

Substance, semi-conductor	$\alpha(\mu V/°C)$	*Substance, semi-conductor*	$\alpha(\mu V/°C)$	*Substance, metal*	$\alpha(\mu V/°C)$
MoS	−770	FeS	26	Bi	−70
ZnO	−714	CdO	30	Ni	−18
CuO	−696	$GeTiO_3$	140	Pd	−6
FeO	−500	NiO	240	Pt	−3·3
Fe_3O_4	−430	Mn_2O_3	385	Al	−0·6
FeS	−200	Cu_2O	474	Pb	−0·1
MgO_2H_2	−200	Cu_2O	1000	Sn	0·1
SnO	−139	Cu_2O	1120	Rh	2·5
CdO	−41	Cu_2O	1150	Cu	2·6
CuS	−7			Fe	16
				Sb	35

Electrical and thermal currents in these materials may result from the flow of electrons or of positively-charged holes left vacant by electrons. Semi-conductors showing these alternative phenomena are known as *n*-type (negative) or *p*-type (positive) thermoelectric materials.

Since $$Z = \left[\frac{(\alpha_1 - \alpha_2)}{(k_1\rho_2)^{1/2} + (k_2\rho_1)^{1/2}}\right]^2$$

it is an advantage if α_2 is positive and α_1 is negative or vice versa.

Much research has been carried out to find methods of improving the thermoelectric power of semi-conductors, e.g. *n*-type bismuth telluride has been given a small excess of tellurium to give extra free electrons, while the *p*-type has a small excess of bismuth to give more holes, i.e. one type has its e.m.f. increased in the negative direction and the other in the positive, so that the difference of these two becomes greater.

It usually happens that thermoelectric coefficients are high when electrical conductivity, $1/\rho$, is low. This relationship can also be changed by adding impurities.

The thermal conductivity, k, of semi-conductors is partly electronic and partly due to lattice vibrations. In this case the lattice vibrations can be reduced without altering the electrical conductivity by adding appropriate impurities.

The best materials so far available for refrigeration purposes are solid solutions of Bi_2T_e, Sb_2Te_3, Bi_2Se_3, all derived from elements of high atomic weight.

It has been found theoretically that the optimum value of Z to fit all characteristics is minus 200 μV/°C for *n*-type materials and plus 200 μV/°C for *p*-type materials.

At present the major problems associated with thermoelectric refrigeration are concerned with materials. Good control of foreign impurities is needed to ensure reproducibility of efficient materials, but polycrystalline material can be used instead of single crystals for economy. This can be powdered and pressed or sintered together into rods and this is done by the Russians for their thermoelectric devices. Hot and cold junctions in these materials may be formed by soldering copper strips between the rods. If necessary the junctions can be connected to compensating blocks, usually of metal, and thermal insulation is also needed between junctions.

Several methods of making contacts of low electrical and thermal resistance at the junctions have been developed, one of these being the use of dental amalgam. More work is needed on this aspect however, since the effect of high contact resistances can be considerable.

Since direct current must be used for the operation of a thermoelectric refrigerator, it will be necessary to develop a low-cost rugged power supply—a certain amount of a.c. ripple, say 10 per cent, can be tolerated, but the inefficiency of the rectifier system will, of course, detract from the performance of the refrigerator.

The construction of a refrigerator can be similar to that of the conventional type, i.e. a cold box can be formed from the cold junctions and the hot junctions arranged to dissipate heat from the back of the system as is done at present by the condenser of the absorption or compression type of refrigerator.

Higher overall temperature differences may be obtained if the junctions are connected in stages, the output of each stage forming the source of heat for the next stage. More than three stages, however, shows little advantage. Good heat exchange with

the air to be cooled or heated is usually promoted by the use of fins attached to the junctions.

Motor-driven refrigerators have coefficients of performance of about 2·0, i.e. two units of heat can be extracted from the cooled body for each unit of power absorbed, expressed in the same units. Absorption-type units have much lower coefficients, usually about 0·4 to 0·5. The thermoelectric refrigerator using presently-available semi-conductors can have a coefficient of performance approaching 1·0, although the values so far obtained are closer to those applying to absorption refrigerators, i.e. 0·5

The first practical refrigerator was made in Russia a few years ago, although the temperature drop which could be obtained by the use of semi-conductors was demonstrated at the Royal Society by the General Electric Company before this. An early Russian refrigerator was made up of two stages of 24 and 60 thermoelements respectively, the direct currents employed being of the order of 5 amperes. The air in the cooled space was reduced to $-4°C$ when the external ambient temperature was 19°C.

TABLE 2

COMPARISON OF ESTIMATED CAPITAL COSTS OF REFRIGERATORS

	Space cooler	*Small refrigerator*	*Small cooling device*
Cooling capacity			
B.t.u./hr.	12,000 (3500 watts)	800 (240 watts)	50 (15 watts)
Vapour compression type			
C.O.P.	2·3	2·0	0·5
Watts input	1500	120	30
Cost	£200	£60	£30 (impractical)
Thermoelectric type			
C.O.P.	0·4	0·4	0·6
Watts input	8600	110	25
No. of cycles	4000	50	15
Cost	£1200	£120	£5

The thermoelectric refrigerator has one big advantage over all other known types: it can be made very small indeed without reducing its effectiveness—and without increasing its proportionate cost. The price of the materials is at present very high although it is decreasing quite rapidly, but even under present conditions a thermoelectric cooler is competitive in the small size range, as shown in Table 2.

If experience in other fields of refrigeration is any guide, the sort of improvement possible from this aspect would be a considerable decrease on these figures. It is thought that in ten years time a small hermetic unit might be competitive, but it may take twenty years to make larger units of 1 to 2 horsepower. The position is more hopeful for heat pumps in the larger sizes because of the lower temperature difference which can be arranged for in special cases, thus increasing the efficiency. The value of Z, the figure of merit, was only $0{\cdot}72 \times 10^{-3}$ °C^{-1} in 1952. In 1958 it had risen to $3{\cdot}0 \times 10^{-3}$ °C^{-1} and it is theoretically possible to reach 10×10^{-3} °C^{-1}.

Other Practical Applications

Because of the possibility of 'point' cooling with thermoelectric refrigerators, several interesting special uses have been made of them. One such use is the cooling of a small area of the interior surface of the glass envelope of fluorescent lamps. The metallic vapours, which gradually evaporate during the life of the lamp and reduce the light efficiency, condense on the cooled area and maintain the quality of the original light.

The facility for cooling small areas has led to the development of microtomes which can be used to cool tissues to the best temperature for cutting very thin sections. Several thousand such microtomes have been manufactured in the U.S.S.R.

Another use in scientific work is a condensation hygrometer made on this principle. The reversibility of heating and cooling operations by alteration of the direction of the d.c. supply make thermostatic control at or below room temperature possible for other purposes.

More utilitarian applications which take advantage of the small size, the easy reversibility and the d.c. operation itself, i.e. the use of accumulators, are the heating and cooling of babies' bottles, the heating and cooling of food trolleys and refrigerators for cars and aircraft.

A great deal of the work described has been carried out abroad, but only recently two British firms have brought out small coolers made on the thermoelectric principle. As the price of the materials is reduced and their efficiency increased, the promise of further interesting developments is likely to be fulfilled.

THE MOON*

By IAN T. BUNYAN *University of Edinburgh.*

At minutes 24 seconds after midnight (Moscow time) on the morning of September 14, 1959, the sudden ending of a radio message at a distance of 23,000 miles from the earth announced to the world that a man-made object had made contact with the nearest neighbour in space, the Moon. Apart from the interest in the Moon which is likely to be shown as a possible base for the future conquest of space, the satellite has attracted interest from the earliest times because of the interesting features it displays, the problems posed as to how it originated and the conditions likely to exist there.

The history of lunar studies could be made in itself the topic of a considerable volume. Only a brief account will now be given, however. In ancient times, the Moon was worshipped as a goddess, being known to the Egyptians as Thoth and Khonsu. Considerable progress was made at this time in study of the Moon's motion so that the times of eclipses could be given to a fair accuracy. The real scientific study of the Moon came with the invention of the telescope by Galileo who, in 1610, used it not only to identify lunar mountains but also to make a map. The advent of Newton's theory of gravitation in the *Principia* of 1687 made possible a quantitative study of lunar motion and form. The first map appeared in 1647, made by one Hevelius of Danzig—about 250 formations were named after terrestrially ressembling features. This work (*Selenographia*) remained the standard work on the Moon for a century. It is to a Jesuit astronomer, Riccioli of Bologna, however, that we owe the lunar nomenclature used today. He adopted the practice of naming formations after mathematicians, theologians, astronomers, etc. In the second half of the eighteenth century, Lagrange and Laplace worked on the position and shape of the lunar body. Schröter, working with telescopes made by Sir William Herschel, in 1791 and 1802, published *Selenotopographische Fragmente* containing drawings of features and also made the earliest determinations of heights of the mountains by their shadow lengths. These were not very accurate due to the poor definition of this reflecting telescope. Lohrmann of Dresden, was more accurate but his eyes failed him before his map could be completed. The standard work, produced as a result of meticulous study by two Germans, Beer and Mädler (*Mappa Selenographica*) and (*Der Mond*) was so authoritative that it effectively seemed to suppress interest until 1874, when Schmidt, who had been working in Athens, produced a twenty-five-section map with a scale of 75 inches to the lunar diameter. The British Association tried to stimulate lunar study and set up a committee with this aim but the death of Birt, Secretary of the Selenographical Society and the lapsing of the Society upset this plan. On the Continent, Krieger made fine drawings, excelling anything previously known. France had Flammarion and Gaudibert drawing up a map. The first great modern map, having a 77-inch diameter, with a scale of 60 inches to the Moon's diameter, was published by Walter Goodacre in 1910. Various fine maps followed, by Wilkins and Andêl in 1924 and a 200-inch map and 300-inch map by Wilkins in 1932 and 1946. At present, study is being carried out mainly by amateurs since most of the larger telescopes are turned to stellar research and, in any case, the small-aperture telescope (6-12 inches) is always revealing new features. With slightly more elaborate apparatus, photographic work has been done by Professor W. H.

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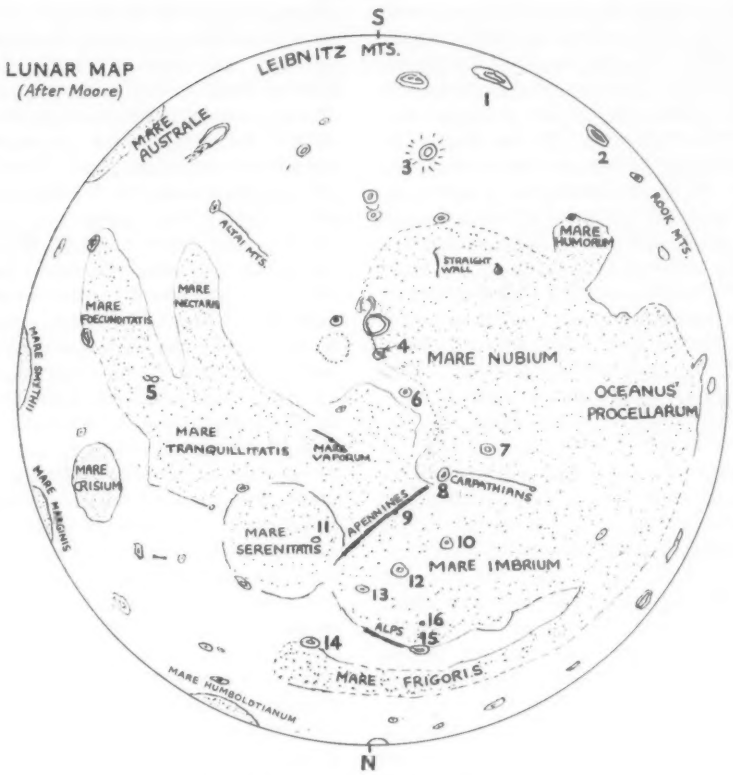
Pickering and a photographic atlas produced by him. Similar work is also being done in Paris by Loewy and Puiseux. The 60 and 100-inch reflectors at Mount Wilson have been used to produce highly detailed photographs, surpassed however, by exceptionally clear photographs from the Pic-du-Midi Observatory in the French Pyrenees. All this research has necessitated a standard lunar nomenclature. This was set up by the International Astronomical Union in 1932 when 672 features were named and catalogued. Recently, Professor Zdeněk Kopal of Manchester University, has started an even more intensive photographic survey under contract to the United States Air Force, with a view to making a 1-cm. to 10-km. map. Already (April 28, 1960) he has taken 15,000 'close-ups' with the 24-inch high magnification refractor at the Pic-du-Midi Observatory and, due to rapid developments in the field of space research, this programme has been speeded up. A new 40-inch reflector has been ordered for the observatory, to be ready next year. This is, incidentally, probably the best major observatory in situation since its height of 9400 feet leaves below one-third of atmospheric disturbance. Mapping is a difficult problem since dust in the atmosphere of the Earth causes image distortion and apparent shift of features by several miles. Shadows on the Moon add to this displacement as does the slight side-to-side turning motion or 'libration' of the Moon in its orbit around the Earth.

In an attempt to get distances and positions right, a reference point whose radial distance from the centre of gravity of the Moon and latitude and longitude are known with utmost accuracy has been chosen. This is a small crater, Mösting A, near the centre of the disc, whose position has been worked out using 10,000 observations of the Moon, made over the past century and collected by Professor Karol Konziel of Cracow. Relative to this point, several other features have been chosen whose positions are known with a decreasing degree of accuracy. These are known as second, third and fourth order points respectively and there are 100, 2000 and 50,000 of them respectively. It is estimated that the first of the new maps will have an error of $\frac{1}{2}$ km.—indeed much of the Moon's surface is better known and mapped than some regions on Earth, and even greater things are promised by automatic photography by artificial satellites such as Lunik III which took the first photographs of the far side of the Moon, in October 1959.

Surface Features

Study of the lunar surface reveals a striking difference in appearance between lunar low areas or 'Maria' and the lighter highland regions. This is thought to be due partly to the larger number of craters in the uplands as opposed to the more level lowlands. The Maria cover half of the Moon's surface, predominantly in the north. Some are irregular, some circular. Some, like Mare Serenitatis, are bordered by mountains and are circular in shape. This formation is connected to another sea, Mare Imbrium, by a gap in the Apennine mountain range. These Maria formations are estimated at 430 and 750 miles in diameter respectively, the latter being the largest of all the lunar Maria. In this area is the object, Linné, which has been the subject of much controversy. When first noticed in 1843, it was described as a crater, five miles wide, by Lohrmann and Mädler. Schmidt in 1866, disagreed with the earlier description, calling it rather, a white cloud. Later observers noted it as a shallow depression in a bright area, then as a crater cone on a small shallow ring. Pickering decided that the original feature, Linné, had disappeared between 1843 and 1866, the shallow crater, taking its place, also having gone by 1897. Speculations are frequent as to the possibility of a real change having taken place, thus evidencing that the Moon is not such a dead world after all. Nowadays, Linné appears to have changed again, since it is now neither a white area nor a depression, but rather a low mound with a deep pit on the summit. On the floors of the Maria are seen occasional large craters, such as Archimedes and Timocharis in the Mare Imbrium, and occasional 'ghost' craters which are probably buried remains of craters older than the Maria. Some of the craters have marked systems of radiating rays (Aristoteles and Tycho). The craters which are found everywhere are so huge sometimes as to be termed 'walled plains' and greatly resemble the Maria. In size they are known to be from 180 miles (Bailly) to 60 miles (Plato) and are more common in the south-east and south-west quadrants of the surface. More numerous than the gigantic walled plains are the ringed plains which have continuous



Main Features described in the Text

(1) Bailly
(2) Wargentin
(3) Tycho
(4) Herschel
(5) Messier
(6) Mösting
(7) Copernicus
(8) Eratosthenes
(9) Huygens (Mt.)
(10) Timocharis
(11) Linné
(12) Archimedes
(13) Aristillus
(14) Aristoteles
(15) Plato
(16) Pico

walls. Often the interior walls are divided by terraces and sometimes a mountain group or crater stands in the centre of the ring (Aristillus). It is to this latter group that the rayed craters belong. Craters proper range in diameter from five to thirty miles and have narrow walls rising steeply from the surrounding country. Again they often have a small central peak. Most strongly akin to terrestrial volcanoes in appearance are the crater cones which are steep conical hills with minute central apertures. Of the smallest size are the crater-pits, often irregular and very plentiful. Mountain ranges are common on the Moon, though they are not so important as the craters. In the north, the Apennines form the most important range with a highest peak, Huygens, of 18,000 feet. The lunar Alps, like their terrestrial counterparts, are very high—the highest peak reaching 19,000 feet. Several other ranges exist as well as the occasional isolated peak, such as Pico.

In the south, mountain ranges are less prominent, the main one being the Leibnitz mountains on the limb of the lunar disc, and containing some extremely high peaks. Common on the great plains are mountain ridges running for great distances but never more than about 200 feet high. The most prominent is the one stretching along the western part of Mare Serenitatis. Valleys are prominent, e.g. a great gorge which cuts through the Alpine range west of Herschel and has a remarkably flat bottom. Clefts or rills are extremely numerous and probably represent great chasms or cracks in the surface not often very wide, but running for hundreds of miles in some cases. Some start off very narrow and widen out, joining with others until a main chasm is reached. Now, since the period of the Moon's axial rotation coincides with its period of revolution round the Earth, one side is always hidden from observation. In distant times, the Moon's axial rotation was probably faster but tidal friction caused by the pulls of the Earth and Sun have slowed it down to a rotation time of 27·32 days about its axis. The slight oscillation of the Moon or 'libration' makes it possible to see some 59 per cent of the total surface but the outer edges are so prone to perspective distortion that accurate exploration is not possible. The flight of the third Russian interplanetary station made possible the first study of the other side. The first photographs suggest that the main difference on the other side is that mountainous areas predominate and seas are few —at least of a size comparable with those on the known side. The problems facing the taking, processing and sending of the photographs automatically from the station must not be overlooked, however, and it would be unwise to generalise from this first experiment since even small focusing errors could give a wrong impression of relief. A prominent feature of the far side is a long (1250-mile) mountain range extending from the south-south-east of the visible Humboldt Sea right into the southern hemisphere. Other prominent features include a 200-mile crater-like sea (named Mare Moscovianum) and craters with a central peak—Tsiolkovskii and Lomonosov.

Origin

When the Moon has been examined, probably the first problem to present itself is that of the origin, both of the Moon and its surface features, since it differs so markedly from the Earth. Satellites may have originated from the same primary cloud as their parent planet. If this were the case, it would be expected that the plane of orbit of the satellite would approximate to that of the parent's equatorial plane. This is not the case. (The Moon's orbit lies 23½ degrees off the equatorial plane.) This, along with the snag of the Moon's large relative size (2160 miles diameter to Earth's 7927 miles) seems to suggest that the Moon is a permanently separated body. Professor Schwarz, of South Africa, has suggested that the Moon and Mercury formed a binary system broken up by perturbations, the Moon being captured by the Earth. Much can be said for the idea of a birth from the Earth and the argument is not closed. The Moon is unique among the satellites in its orbit, which is completed mainly outside the main gravitation sphere of the parent body. In fact, it is not like a satellite orbit at all, being more like that of an independent planet's orbit. Firsoff describes the perturbations produced on the Moon as causing it to swing around the Earth in a 'kind of flat scallop'. The Moon's orbit is subject to tidal evolution. The total angular momentum of the Earth–Moon system is constant and is made up of the revolution of the Earth and Moon around the centre of gravity of the system and their respective axial spins. This momentum is always undergoing redistribution between the two by the action of tides, which cause friction, slowing axial rotation and hence increasing orbital motion. In the past this action has so slowed up the Moon's rotation that it has now always the same face pointing to Earth. Since the Moon is so large, it produces a similar effect on Earth just now which is considerable. At the moment, the Earth day increases by 1 second per 120,000 years. As this slowing increases, so redistribution occurs, and the Moon's orbital speed is increased which causes recession of that body with a consequent increase in the length of our month. The slowing up of the Earth is enhanced by solar tides. Eventually, the length of our day and month will become equal, barring other effects, and then, solar tides will further slow the Earth and the Moon, and, it is reasoned, tend to cause a reverse process to the above, when a reapproach will occur. Darwin and Jeffreys have extrapolated back this tidal evolution

and found that when the Earth was turning once round in four hours, the two bodies would have been in actual contact. This gave rise to the idea that the Moon was born out of the Earth when in the molten state and just beginning to harden. The Pacific is pointed out as the scar left by the separation. This theory, however, meets almost insuperable difficulties at the outset, for it is known that a large mass closer to a planet than a limiting distance (Roche's limit) is torn apart by tidal action the small pieces going into orbit like Saturn's rings. If the capture theory is accepted, it could be expected that if this occurred recently, the planet must have had a very eccentric orbit. With an original orbit near Mars the tendency would then be for a drastic reduction of rotation speed, and orbital velocity increase to give a more circular orbit with the orbital revolution period approximating to the axial spin period. A study of the rocks can give us no clue as to the length of day on Earth in the past, but if the diurnal spins of Earth and Mars—a planet with no large satellite—are compared, they are found to be the same. This fact suggests that, if the two had originally the same spin period, as is quite possible from some theories of the origin of the solar system, the Moon has not been present long enough to produce appreciable slowing of the Earth's rotation compared to Mars, and hence the Moon's capture must indeed have been recent geologically. However, the stabilising effects of solar tides may be such as to keep its planets' axial revolution at a constant rate over vast ages, regardless of satellites.

The large number of upheavals in the Earth's geological history suggest another alternative. The catastrophies could be explained by a series of close approaches of the Moon, followed by the rapid slowing of rotation. The Moon's surface shows two fault lines trending west-south-west to east-north-east which could be explained by the titanic deceleration which such an approach would produce. Further, the distribution of ice-caps seems to have shifted at least three times during the traceable past during the Cambrian, Permian and Quaternary Periods when the rocks show evidences of glaciation in lands previously very warm. These two factors may correlate—vast disturbances taking place on each planet at the same times on three captures of the Moon—for example, the shift during the Quaternary producing the last Ice Age may correspond to the foundering of a large dome to produce the Mare Imbrium. Spurr suggests three main phases of crater formation on the Moon and a study of the tectonics by Firshoff has suggested a series of three feature formations which may coincide with the terrestrial mountain formations of the Cambrian, Permo-Carboniferous and Tertiary disturbances. The cyclic process suggested by Firshoff on the above evidence is (1) an approach of the Moon, rapid rotational deceleration with mountain formation and vulcanism on both bodies—the Moon exhaling gas bubbles and shrinking, producing rotational acceleration with the consequent repulsion due to tidal action already mentioned. (2) with the Moon at a distance, conditions quieten down on both planets but there is a gradual reapproach with the cycle being repeated.

A very recent theory for the origin of the Sun's planetary system put forward by Professor Hannes Alfvén of Stockholm suggests that electro-magnetic forces played a greater part in the formation of the solar system than earlier theories such as the Nebular Hypothesis of Laplace or the Planetesimal Theory of Chamberlain and Moulton. He postulates a Sun condensed from a magnetic cloud of gas and thus having a strong magnetic field. There was, however, some residual magnetic gas at a distance from the Sun and not condensed. The ionised gas was prevented from falling into the Sun by its own magnetic field and that of the Sun. Un-ionised gas would fall into the Sun under gravity. The initial de-ionisation of some of the gas took place during cooling. It was a selective process, those elements present in the cloud with the highest ionisation potential being the first to de-ionise. As these fell towards the Sun, other elements in the cloud with lower potentials de-ionised and so several differently constituted clouds designated A, B, C, D clouds with A at highest ionisation potential were formed. As the clouds fell, their speed increased and if great enough, on collision with the permanent ionised layer around the Sun, ionisation of cloud material could occur. A braking effect, due to the Sun's magnetic field reacting with the ionised gas, would be produced and the clouds would be stopped eventually at distances according to their ionisation potential, going into orbit around the Sun. The A cloud, it was suggested, was stopped $2{\cdot}25 \times 10^{13}$

cm. from the Sun, i.e. about the present distance to Mars and from it condensed Mars and the Moon, by accretion of dust condensed from the cloud. The B cloud having different composition and velocity, ionised and began condensation similarly at $1{\cdot}09\times10^{13}$ cm. From it, Mercury, Venus and Earth formed. Due to overlap between the regions newly formed, Earth captured the Moon. This theory is so recent that criticisms of it have not yet been put forward but it does fit in well with the evidence that the Moon was not a part of the Earth in the past at any time. Firshoff's ideas about repeated approach and regression could further fit in well with this hypothesis.

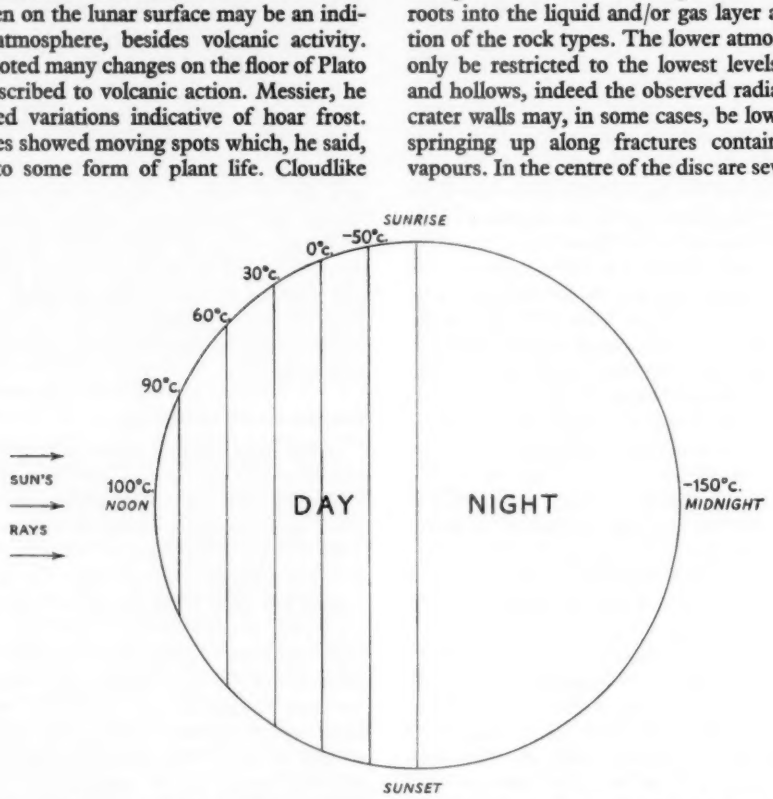
A theory of the past history of the Moon should be borne out by the composition of that body. Further, a theory of its origin may depend on what can be shown to have caused the surface features. Various materials have been suggested for the composition of the lunar surface. Spurr suggests the name 'Lunarite' for the light rocks of the surface and 'Lunabase' for the darker material, possibly a light acid granite and a darker basalt. Indeed, by measuring the amount of sunlight absorbed by the Moon and comparing the result with the absorption of sunlight by terrestrial materials (i.e. the mass absorption coefficient) the Moon's surface would appear to be basaltic. This would appear to suggest a volcanic rather than a meteoric origin for surface features since the mass absorption coefficient for meteoric material is much too high for the Moon's surface to have been liberally scattered with that material. The volcanic origin of lunar features is the earlier proposition. Doubts were first being cast by Gilbert in 1893 who noticed that the dimensions of lunar craters were not anything like volcanic craters on Earth, but the further evidences for the volcanic explanation should be discussed first. The ring mountains are suggestive of a surface contraction over an unyielding interior but this will not account for the frequently observed central peak of some of such formations. The suggestion is that the Earth and Moon being close at an early time, before the Moon was completely solid, tides were caused in the lunar subsurface with consequent upsucking of magma and spreading this out over large areas as circular pools. With an increase in distance of Moon to Earth, concentric ridges and terraces were formed, by retreating tides, the lost magma leaving the central cone. The Earth need not be brought into the discussion, for features could be explained by a lunar surface in a semi-molten state with gas liberation in the cooling skin. Bubbles were formed which soon burst and subsided forming the ring features. Alternatively, gas-rich magmas intruded underground might heave overlying rocks into domes or 'laccoliths' which collapsed (some may have formed the seas). It is doubtful if activity penetrated the surface to a violent degree, possibly due to lightness of overlying rock. Domes in the Mare Imbrium (some forty miles wide) may be uncollapsed laccoliths. The violent deceleration of the Moon or meteor bombardment may have opened fissures. Even more surprising theories, but nevertheless feasible ones, have been put forward. The radial gullies surrounding the Archimedes area, Aristullus crater for example, are suggested as having been worn by rain from the steam produced by their eruptions. The fact that the rays seen radiating from some craters such as Tycho, are deviated by even small obstructions can only suggest that if they were formed by ejection, this was slow and unenergetic. Possibly eruptions, if they occurred at all, were of the type found in the Hawaiian islands on Earth with a very fluid basalt lava but not a violent explosion, tending, in the case of the Wargentin, to fill up the crater. A strong piece of evidence for volcanic origin for lunar features is the fact that many craters appear to be definitely aligned on the surface with even spacing, possibly on lines of structural weakness as on Earth. The general conclusion about the lunar volcanics appears to be that it was in the nature of a slow leak! Not all study of materials leads to the idea of volcanic activity. The difficulty of spotting any definitely recognisable volcanic feature led to other ideas. Gold, in 1955, argues strongly for a meteoric origin to Maria as well as the craters. He accounts for the smooth appearance of certain areas in the Maria, etc., by an erosional system causing dust in the highlands. (Certainly the braking down of rock by exfoliation will be a slow process due to lack of atmosphere but cumulatively it will probably produce a vast amount of material.) A transport system to the lowlands could be by an evaporation-condensation process, or electro-static forces, or even a degree of seismic activity to produce the smooth plains. He explains the dark

areas further as being due, not to basalt, but to radiation damage by solar X-radiation, ultra-violet and corpuscular radiation. Certainly temperature measurements of rates of temperature-fall in the Mare Vaporum during an eclipse in 1927 (by Pettit and Nicholson) rule out bare lava as the basis for the smooth areas and rather suggest a layer of dust over a good thermal conductor. Comparison of the polarisation of moonlight with light reflected from terrestrial materials suggests a pumice powder (Wright, 1927). This dust layer hypothesis is supported by recent experiments in sending radio signals to the Moon aimed at certain areas. Radio wave results for the temperature on the Moon's surface do not agree with the cycle measured in the infra-red. This is a clue to the surface layers being composed of a substance, transparent to the 1·25-cm. radio waves. The temperature variation being measured by radio will thus originate at various depths. If the surface layers have an appreciable thermal capacity, the temperature variation at depth will lag behind that at the surface. On the other hand, the surface is opaque to infra-red radiation, so that its measurement will give surface temperature. Piddington suggests that the transparency to radio waves is due to a dust layer which may be meteoric debris and estimates a 40-cm. depth. Further weight was added to the meteor theory by experiments by Vanfleet and Partridge in America in forming lunar-type craters by firing pellets at tangents at velocities of 1–3 km./sec. since, in the absence of an atmosphere, it is calculated that the minimum impact velocity is 2·4 km./sec. The materials used were wax, plaster of Paris or metals and the resemblances obtained to lunar craters were strong, i.e. (*a*) same shape, (*b*) amount of material in the crater lip and raised portions of the surface was equal to the volume of the crater, as Schröter observed on the Moon, (*c*) ray systems extending from the crater centre, (*d*) wrinkled appearance around metallic craters, due to slipping of crystal planes, closely resembled some lunar features, (*e*) it was possible to form impact craters with central peaks, a vexed problem for those who supported vulcanism. It was found that rays were not produced by smearing of the surface with missile debris, a fact which was not easy to explain on the Moon, but by crystal plane slippage in target material. Oblique angle shots produced further similarity in that, if the angle of impact was 82·5 degrees from the vertical, two distinct craters were formed. This may account for seemingly large numbers of lunar impacts. Paired craters were produced by a further angle increase. The peaks were produced by hard pellets deforming and fracturing on impact, part of the material remaining and taking the form of a small peak. A similar effect was produced by any pellet with a hole in its impacting surface. The meteor theory has its snags; rays do not always coincide with the apparent impact site. No meteor swarms appear to have decimated the earth. (Note. This can be explained by recession of the Moon or initial independence and erosion of any meteor damage on Earth.) Much is to be said for both theories although the former seems to have a slightly stronger support at present.

Conditions on the Moon

If the Moon had an appreciable atmosphere, it should refract the light of stars shining beyond it. Pickering and Cornstock have noticed a slight effect and Pickering inferred a ground density 1/8000 of our own. However accurate this may be, it is not enough to give a halo during the Sun's eclipse but even if the density of the atmosphere were only 0·0001 of ours, scattering by the gas high above the surface would produce slight illumination of the disc beyond the terminator (line between brightness and darkness) and this has been reported to an extent giving an atmosphere 0·0001 of ours. (This estimate is again debatable.) Another source which suggests the Moon not to be the airless globe previously imagined is the fact that in occultation of stars by the Moon a blue flash similar to the flash produced sometimes in Earth's atmosphere after sunset, has been suspected by lunar observers. Lunar meteors have also been reported, another fact suggesting some atmosphere (Haas). The Moon, of course, has low gravity and so will tend to have lost the lighter gases not long after formation since they would only need a velocity of $1\frac{3}{4}$ miles/sec. to escape. However, some carbon dioxide and water may remain along with low-lying layers of sulphur dioxide and vaporised Mercury, Phosphorus, Potassium, Sodium—all of which boil under lunar day conditions. The currents created by ionised gases caught by the four traps in the container

of Lunik II provided new data on the possible existence of an area of ionised gas or a lunar ionosphere within some 6000 miles of the Moon. The changes seen on the lunar surface may be an indication of atmosphere, besides volcanic activity. Pickering noted many changes on the floor of Plato which he ascribed to volcanic action. Messier, he said, showed variations indicative of hoar frost. Eratosthenes showed moving spots which, he said, were due to some form of plant life. Cloudlike seeped through from the surface. Certain areas which show colour variation during the day show changes consistent with vegetation having long roots into the liquid and/or gas layer at the junction of the rock types. The lower atmosphere may only be restricted to the lowest levels of craters and hollows, indeed the observed radial bands on crater walls may, in some cases, be low vegetation springing up along fractures containing useful vapours. In the centre of the disc are several green-



Lunar Temperatures (approximate) (*From measurements by Pettit and Nicholson*—After Whipple.)

formations along the face of the Apennine mountains were also mentioned by him. Certain craters vanish and reappear at intervals, suggesting obscuration by some type of atmospheric material. All this information contradicts the previous view of the Moon as a dead unchanging world. It may thus possess a highly tenuous outer gas envelope with a very shallow denser layer. The lower mean density of the Moon would certainly mean an abundance of the biologically important lighter elements in the crustal surface, i.e. in the pumice. Where this area meets lower impervious rock, we might expect to find water and gas which had hued spots which are definitely due to a surface phenomenon of the rock which may reasonably be vegetation in a very shallow layer. Bacteria are known which thrive on sulphur and boracic acid, both of which may be present in the Moon's atmosphere. We need not be concerned with the ability to survive under such conditions (see diagram)—mosses can stand up to below −50 degrees C. in the Arctic and down to even −35 degrees C. Lichens can be immersed in liquid air (−109 degrees C.) and spores will reproduce after being exposed to vacuum and the −271 degrees C. of liquid helium. The low gravity may remove one

of the main struggles which life on Earth has and thus reduce energy requirements of life there.

The Moon is a fascinating object for study but it must be admitted all through that the answers to all the problems here discussed—problems of origin, composition, etc., lead with the present indirect methods of observation, to speculation. It is to the future we must look, to the possibility of direct observation on the surface of the Moon itself for the final solutions of those problems which have baffled men for centuries.

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THE FLOWER AND THE BEE*

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'The might of Britain depends on its old maids.' Old maids keep cats. Cats kill mice. Empty mouse holes form good nesting places for bumble bees. Bumble bees pollinate red clover, clover feeds beef—beef gives Britons their drive and energy!

Even if this chain reaction appears somewhat fanciful, we have abundant evidence that our crop economy is geared to this amazing strong, yet delicate, link between the plant and insect kingdoms—between *the Flower and the Bee*.

I want to discuss some facets of this remarkable relationship and to indicate current lines of research in this field, which are biased, as you might expect, towards man's attempt to exploit it and profit by it.

Pollination

All flowering plants are highly specialised organisms, and one result of this is that there is a separation in space between the male and female organs in the flower (stamens and ovaries), so it becomes necessary for the pollen to be carried in some way or other over this spatial barrier. This transference and placing of pollen grains on the receptive stigma of the ovary is what we term *pollination*—whether or not *fertilisation* and seed set follows is entirely due to whether the right kind of pollen has been placed on the stigma.

Wind, water, birds and insects may all act as pollinating agencies and bridge the gap, not only in individual flowers, but between one flower and another or between one plant and another effecting cross-pollination.

Many floral forms make self-pollination virtually impossible and establish an *outbreeding* mechanism for the species.

* Semi-popular lecture delivered to Section K (Botany) at the Cardiff Meeting of the British Association.

This appears to be a present-day evolutionary platform in many Angiosperm species. But will it remain so? The dandelions and hawkweeds have already evolved to another method of reproduction, *not using pollen at all*. They are *apomictic*, i.e., their seeds develop without fertilisation. Although their flowers still exhibit a beautiful mechanism for cross-pollination by insects backed up by a liquid inducement of concentrated nectar, it is obsolete. Try it yourselves by cutting off the stamens and styles of a dandelion head: it will still set good seed.

Entomophilous flowers, i.e. those pollinated by insects, exhibit many features which we find pleasing—colour, scent, form—but bees only visit flowers for food, pollen and nectar for rearing their grubs, for their daily needs, and, in the case of the *honey bee* for winter store as honey or packed pollen. An inhibitory substance in the pharyngeal glands of the bee prevents *germination* of pollen in cells which would possibly ferment the honey and ruin the winter store. But we now know, as a result of many fine researches on the senses of the bees, that these other attributes (colour, scent, form) have a meaning for the bees and therefore assist in attracting them as pollinators.

The delicacy and precision of the bees senses can be judged from the following facts:-

Sense of Smell

Bees can distinguish, recognise and remember flower scents. They can pick out one flower perfume from amidst thirty others. They are also very sensitive to the scent they themselves extrude from their abdominal scent organ.

Colour Sense

They can distinguish, recognise and remember three regions of the visible spectrum and ultra

violet. This latter is a very real 'colour' for the bees and some flowers which appear self-coloured to us may be exhibiting a colour contrast for the bees eyes. For example, in *Mimulus* and the *Yellow Flag Iris* the opening to the flower tube is shown by strong ultra-violet radiation from the petals at this point. The bee will perceive this as a guide to the nectar of ultra violet on a yellow ground.

Sense of Taste

Bees can appreciate degrees of sweetness and even show preference for certain mixtures of sugars. Dr. Raw of Rothamsted reported that consistent preferences were shown for single sugars in the following descending order:

(*a*) sucrose;
(*b*) glucose;
(*c*) maltose;
(*d*) fructose;

but when a mixture was offered, an anomalous high preference for sucrose–glucose–fructose solution, which was quite different from predicted preference on the basis of an additive effect of the constituent sugars.

Recently it has been shown that the families which contain so many 'bee' flowers actually have this mixture of sugars in their nectar.

Also in several 'climax' groups of plants such as the Crucifers (cabbages), the nectar is composed of simple digestible monosaccharides—fructose and glucose—in virtually the same proportions as are found in honey. So, many of these highly evolved 'modern' plants are producing a nectar which is technically a 'honey' already. The digestive invertase of the Hymenopteran (bee) visitors is not required! The nectar can be assimilated immediately by the insect. Has this any biological significance?

To return to the bee senses. Von Frisch has proved that the bees can communicate their sensual experiences to their hive mates by dancing and hence recruit workers to forage a particular crop.

But this emphasises a difference between the hive and bumble bee. Honey bees do not connect the flowers with food instinctively and have to learn that their food is in the flower. Whereas a novice bumble bee worker on her first foraging flight will fly straight to a flower.

Time Sense

This is highly developed in the honey bee. There is some evidence that this may be employed in pollen collecting. It has been found that different species 'present' their pollen at different times of day, e.g.:

Poppy	early morning (peak 6 a.m. (5–10 a.m.))
Dandelion	morning (peak 10–11 a.m.)
Raspberries and blackberries	all day
Broad beans	afternoon (12 noon–3 p.m.)
Vegetable marrow	night (10 p.m.–3 a.m.)

In a number of species the rhythm of pollen presentation shows a positive correlation with the rhythm of pollen collection by the bees. For example, in the Water Plantain pollen is presented from 11 a.m. to noon. Just before 11 a.m. bees will arrive and scout among the plants to see if any flowers are open (flower opening and anther dehiscence is simultaneous). It is not only bees which have this time sense. In the early morning, hover flies have been seen clinging, head downwards, on the undehisced anthers of maize, lipping around the terminal pore of the anther and waiting for opening time. So this time sense can be employed for the mutual benefit of both plant and insect for in all cases of bees collecting pollen it was seen that pollination was also effected.

Rapidity of Learning

This is a striking feature of honey-bee psychology. To quote one, e.g., a 'Novice' bee on maize searched in between the glumes of the male flowers for 'something', then by chance passed under a group of stamens and dislodged some pollen on to herself and immediately turned on to her back and began to collect pollen.

Individual Traits

Bees exhibit quite individual traits in collecting nectar and pollen. The pollen collectors are like women shopping, some neat and expeditious in their pollen packing, others much slower. One working the broom by shouldering between the standard and keel of the young flower, was able to remove all the pollen without springing the flower.

Then there are those bees which the American orchardists call 'stinkers', which take the nectar from apple-blossom while clinging to the outside of the flower, thus failing to pollinate them.

And here is a link between bee physiology and flower physiology. In early spring, fresh pollen is urgently required by the bee colonies for brood rearing. Flowers blooming in February, March and April require a temperature of from 8·8–10° C. (50° F.) for free anthesis (free production of pollen). 10° C. has been stated to be the limiting temperature for (hive) bee flight; inaction of the wing muscles is said to occur below this. It is seen that the February–April flowers have pollen available at a slightly lower temperature than this. So there is a pretty balance here, the bee food being available in the flowers at just about the same temperature level that the pollinating insect can fly. There is yet another parallel. Crocus and snowdrop flowers open at 4° and 5° C. respectively if in sunlight, and the bees were seen working these crops at 4° and 5·7° C. respectively if it was sunny. So direct sunlight compensates for the lower air temperature at a comparable level for both insect flight and flower opening.

There are other attributes of bee psychology which facilitate pollination. *Constancy* is one of the foremost of these. Coupled with the honey bee's sense of location it is immensely valuable to agriculturalist and orchardist. As long as the food —be it nectar or pollen—is plentiful, the bees will continue to visit a crop exclusively. But there is a danger in this very constancy, for, other things being equal, bees will be attracted to crops with the strongest nectar. They may even select individuals in *one crop*.

Take the case of the orchardist. Cross-pollination is essential for fruit set in certain 'self-sterile' varieties of apple (or plum), so orchardists frequently plant a mixture of varieties in the expectation that the bees will effect this.

But see what happened in an American plum orchard. Three varieties were planted, the sugar concentrations of whose nectar differed considerably:

Maynard	10·1 per cent sugar in nectar
Eldorado	14·9 " " " " "
Milton	28·4 " " " " "

Milton attracted most bees and was well pollinated, and note that it would receive pollen from its own race. Now, if the variety is self-fertile, this is satisfactory, its 'pollination potential' is high if honey bees are the pollinators. If however, taking a hypothetical case, the variety was self-sterile its pollination potential would be very low.

This would also be so if it was self-sterile (or fertile) and had very weak nectar. It would only succeed in being cross-pollinated if it could compete on even terms, as regards nectar concentration with neighbouring varieties for the bees' services.

So a plant may miss the biological bus in this way. Another example of this is recorded by Vansell in Oregon.

Some plants have nectaries outside the flowers, e.g. on leaves, petioles, stipules, the so called extra floral nectaries:

Plant	*Nectar*	*Percentage sugar*
Common Vetch	blossom	22·6
" "	stipular	56·5
Hungarian Vetch	blossom	25·2
" "	stipular	47·7

The bees work stipular nectars assiduously and neglect the flowers—these species have also missed the bus!

Another example of biological misfortune occurs in the loco weed (*Astragalus lentiginosus*), Nevada, and the buck eye (*Aesculus californica*). Both produce poisonous nectar, containing selenium and alkaloid, respectively. These are deadly to bees and *Aesculus* is particularly dangerous because the nectar is very concentrated (almost supersaturated). Even the movement of a flower may prejudice its pollination potential. For example, when a bee alights on a *legume* flower, she 'trips' it. The wings and keel are pressed down and the stamens spring up and shower her with pollen. This latter action in Alfalfa (*Medicago sativa*), is so violent and deals the honey bee such a shrewd blow, that some workers say she is disconcerted and deterred from further foraging. Dr. Nielsen in Denmark has found a strain where the staminal column is nearly straight and does not strike the bee. It may have an economic future.

Interdependence of Flowers and Bees

Bees will exploit any flower in which they find 'good' nectar (probably that containing over 18·0

per cent sugar) but some flowers with deep-seated nectar in long-tubed flowers are dependent on bees for pollination. This link may be very close, e.g. in certain *Aconitum* spp. (Monkshood), where the geographical range of the species in Europe and the range of certain long-tongued *Bombi* is said to coincide. There are other close links.

There is sometimes a coincidence of the 'imago' stage of some wild bees and the flowering of certain plants, a classic example being the Pickerel Weed (*Pontederia cordata*) and the Pickerel Weed bee (*Halictoides novae-angliae*). The flowering of the former coincides with appearance of bee, and it is believed that the bee does not visit any other plant for nectar or pollen. It is a *monotropic* bee.

Others are 'oligotropic', the Vernal Andrenas visiting only species of Willow and the Autumnal Andrenas visiting only species of Golden Rod.

Dr. Gorton Linsley reports that perhaps the most exquisitely precise bee-flower associations occur in the Californian desert between a species of *Oenothera* (Evening Primrose genus) and a black solitary bee (Anthophorid). Before dawn it is cold, dark and silent. As the first light comes, the flowers of the *Oenothera* open their petals and face the place where the sun will rise. As the sun strikes them, the stamens, which stick out in front, release their pollen. At this very moment, the black bees arrive, land on the stiff stamens, and whip off the pollen (and pollinate the flowers). The desert is bright with flowers and humming with bees. In an hour, the flowers have collapsed limp and dying in the hot sun, the bees have disappeared into cool crannies and all is still and dead once more.

But even more delicate timing may occur. Dr. Linsley says that in that one hour of desert life, he has seen a succession of five different species of bees work the flower. The bee which works for the first ten minutes is the largest kind and the other 'ten-minuters' successively smaller.

Bee Behaviour and the Evolution of Plant Species

The behaviour of bees may vitally affect the evolution of plant species. Related species growing wild may occupy the same range without apparently hybridising but when brought into breeding plots will hybridise freely! So the barriers to interbreeding cannot involve incompatability or hybrid sterility.

But it may be that interspecific pollination is not occurring in the wild because the pollinating systems of the plants are acting as isolating mechanisms. Verne Grant (U.S.A.) says this could be because (1) the floral mechanisms of the two species may differ, so that a bee pollinating one, cannot pollinate the second—he calls this *mechanical isolation*—or (2) the bees are 'specific', or constant to a species. Here cross-pollination is mechanically possible but does not occur because of bees' flower constancy. He calls this '*ethological*' *isolation*.

This latter type does exist among three subspecies of *Gilia*. Two of these have lavender flowers and sweet scent and the third smells of creosote, and is deep violet.

Subspecies	*Colour*	*Scent*
Gilia capitata capitata	lavender	sweet
G. capitata tomentosa	lavender	sweet
G. capitata chamissonis	deep violet	creosote

Eighty plants of these three were randomised in a plot. If a bee visited the 'creosote' plant she remained constant to it (although investigating flowers of the other two). Others worked the two 'sweet' subspecies with free interchange. This isolation held during spring, later in summer some bees on 'sweet' subspecies occasionally visited the 'creosote' flowers and vice versa but this was not customary. These field observations were reinforced by sowing the seed of all the plants and classifying the progeny as subspecies or hybrids.

The two 'sweet' subspecies produced 58·7 per cent hybrids, but there was no contamination of these two by pollen from the 'creosote' subspecies. So here one subspecies was, by the bees' action, kept genetically pure, while heterozygosity was impressed on the other two. This kind of bee behaviour might possibly be a useful tool in the hands of the geneticists.

Two of the most important fodder crops in the world today are alfalfa and red clover. The demand for red clover seed exceeds the supply, and red clover is dependent on long-tongued bumble bees for its pollination. Realisation of this important fact has been slow, resulting in such mistakes as the introduction of red clover into New Zealand, where there were no indigenous *Bombi*.

The New Zealand story is particularly interest-

ing. The error was remedied by the importation of four species of British bumble bees (1884–5) with phenomenal success. (But even this was faulty, because one of these was *Bombus terrestris* which has a short tongue and robs the flowers of their nectar by biting through the base of the corolla tube without effecting pollination.) Yields of 400 lb. of seed per acre was averaged on the plains and, in the valleys in the hills, a prize field reached 1100 lb. per acre. Then in the plains the yields gradually dropped to 170 lb. per acre. What had happened? The bees were still there, but they had become adapted to the New Zealand climate. When first exported, they produced colonies with plenty of workers at the time when the clover was in flower. Then, gradually, their habits changed. The queens ceased to hibernate and remained active all the year, so that, to quote Mr. Anderson of the New Zealand Grassland Division of the D.S.I.R., 'the colonial maxima are now much more widely spread over the year'. So the problem had to be tackled again. Dr. Elwood Montgomery (U.S.A.) suggested that the American species *B. impatiens*, which is specially adapted to life on the plains might be introduced. The Department of Agriculture endorsed this policy but the beekeepers opposed it, because they thought it would reduce the honey crop, and they also feared the introduction of acarine disease.

Now, the tube of the flower is too long for the honey bee to exploit red clover for nectar, although they may visit it for pollen. Nevertheless, the introduction was stopped, but an educative campaign initiated by Dr. Montgomery bore fruit, and reconciled the beekeepers to the government policy. But Mr. Anderson says the scheme has not yet been implemented. (This account is given in no spirit of criticism but just as an illustration of what can happen when a biological system is not fully understood.)

What of the position in other countries? Today, in parts of America and in Scandinavia the natural population of bumble bees has been so diminished that the position is becoming critical.

Intensive methods of agriculture are responsible for this, involving, as they do, the destruction of nesting sites by the cutting down of woodlands, elimination of 'rough' ground and the use of fencing posts as boundaries instead of hedges. Other contributory causes are, the spraying of crops with insecticides when they are in bloom—particularly orchard trees, and the diminution of the natural flora by use of selective weed killers especially along roadsides and grass verges.

The majority of papers at the 'Symposium on Pollination' held in Copenhagen last August dealt with the problem of establishing adequate numbers of the right species of bumble bees to pollinate alfalfa and red clover. Indeed, in the States they are experimenting in the domestication of bumble bees. As the 'fall' approaches, wooden boxes, filled with sphagnum or dried grass and baited with corn, are placed along fences and edges of woods. The mice are attracted to hibernate therein and they 'work up' the moss into 'desirable residences' for the queen bees next spring! Both Danish and American workers report a substantial increase in worker bees in the domesticated colonies.

In Britain, the light stands at amber—we cannot afford to let it turn to red. It is not enough to encourage beekeeping. As Dr. Linsley (U.S.A.) says: 'You cannot expect the honey bee to be all things to all crops.' We must educate ourselves, our local councils, countrymen, farmers, orchardists and market gardeners to aid in halting the appalling destruction of our wild bees. We must remember that without the wild flowers of our road verges, meadows and hedgerows, our bumble bees cannot support themselves until we need them to pollinate our clover. Indeed, in Denmark, *Early Red Clover* is cut in May to delay flowering until bumble bee colonies have built up sufficiently to pollinate it adequately.

BRITISH ASSOCIATION NEWS

NORWICH MEETING

August 30—September 6, 1961

The Humanity of Man

Sir Wilfrid Le Gros Clark has chosen 'The Humanity of Man' as the title of the Presidential Address which he will deliver in St. Andrew's Hall, Norwich, on the evening of August 30—the opening day of this year's Annual Meeting.

A final programme, which will give full details of the scientific programme of the meeting, including the names of the 200 or more speakers and the titles and summaries of their contributions, will be published during the first week of August, and copies will be sent to all those who have registered their intention of attending the meeting or who apply for one. An indication of the wide variety of topics of both fundamental and current interest which will be discussed in the programmes of the fifteen different Sections is given by the titles chosen by the Presidents of the Sections for their addresses:

The Interior of the Earth, by Dr. R. Stoneley, F.R.S.

Chemistry and the spectroscope, by Prof. R. G. W. Norrish, F.R.S.

Black shale, oil and sulphide ore, by Prof. K. C. Dunham, F.R.S.

Life and environment on the bed of the sea, by Prof. C. M. Yonge, C.B.E., F.R.S.

Technology and geography, by Prof. S. H. Beaver.

The economic use of brains, by Prof. C. F. Carter.

World communications, by Sir Gordon Radley, K.C.B.

Dating man's emergence, by Dr. K. P. Oakley, F.B.A.

The sensory nervous system, by Prof. Sir Bryan Matthews, C.B.E., F.R.S.

From Galton to Crowther, by Prof. George Seth.

Plant taxonomy as a scientific discipline, by Dr. R. E Holttum.

Wood anatomy, by Dr. L. Chalk.

Education in Uganda, by Dr. B. E. Lawrence, C.B.E.

The revolution in agriculture, by Sir William Slater, K.B.E., F.R.S.

African jurisprudence, by Prof. Max Gluckman.

Science and social service, by the Earl of Cranbrook, C.B.E.

Young People's Programme

A special programme for young people in schools in Norwich and its surrounding region is being arranged and, as last year, will include four illustrated lectures, a 'Brains Trust' under the Chairmanship of Dr. W. E. Swinton, and a 'Science in Schools' exhibition.

The York lecture will be given this year by Professor O. R. Frisch, O.B.E.. F.R.S., under the title of 'The fundamental particles of physics'. Professor Frisch, who has been Jacksonian Professor of Natural Philosophy at Cambridge since 1947 was born and educated in Vienna, and carried out research on atomic and nuclear physics in Germany, Denmark and the United States. He was co-author with Professor Lise Meitner of the paper in which the term 'nuclear fission' occurred for the first time.

On the following day, Friday, September 1, Dr. Maurice Burton will talk on 'Everyday events in the lives of animals'. Sir Raymond Priestley, M.C., who was President of the British Association in 1956, will speak during the afternoon of Monday, September 4, on 'Antartic exploration, yesterday and today'. Sir Raymond was a geologist on the Shackleton Antarctic Expedition from 1907 to 1909 and is today the sole survivor of the Northern

Prof. O. R. Frisch
(By courtesy of Lotte Meitner-Graf)

party of the Scott Antarctic Expedition of 1910–13. Finally, on Tuesday, September 5, Dr. J. B. P. Williamson, who carried out research under Dr. F. P. Bowden, in the laboratory of the physics and chemistry of solids in Cambridge and is now in charge of research into welding and switch gear phenomena at the Tube Investment Research Laboratory near Cambridge, will lecture on 'Friction and wear in the space age'.

While these lectures are primarily intended for young people in the Vth and VIth forms in schools in Norwich and its region, tickets will also be available at the Meeting to members of the Association and their families. A detailed programme of this Junior B.A. meeting will be published as part of the main programme of the annual meeting referred to above.

Science for All

For the sixth year in succession the National Book League Exhibition *Science for All* will be shown at an Annual Meeting of the Association. Each year the exhibition (about 400 volumes in all) is brought up to date by the addition of new books published during the intervening twelve months. These range from the popular to the advanced amateur level, the aim being to cater for 'the general reader' of all ages and stages. Few people leave school nowadays without at least a background of scientific knowledge undreamt of by their parents. Yet those parents, or many of them, feel the need to acquire some grasp of the basic facts, not only in order to keep up with their offspring, but essentially to understand what's going on in the world at large. In consequence there is a steady flow of books to enable the casually curious, the genuinely inquisitive, and the serious amateur, to pursue their interests. It is, thus, a cross-section of non-specialist books on the physical and biological sciences (excluding medicine) that the N.B.L. presents in their exhibition each year. Notes on many of this year's new titles have already appeared in the columns of *The Advancement of Science*. This year there will be, in addition, a small collection of books on current affairs—political science and economics.

After being shown at Norwich, the exhibition will be shown in many parts of the country as one of the NBL's touring exhibitions.

GRANADA LECTURES

The third annual series of Granada lectures on problems of communication in the modern world arranged by the Association in conjunction with Granada TV Network Limited, will be held in Guildhall, London, during October of this year. Sir James Gray, C.B.E., M.C., F.R.S., will lecture on Tuesday, October 3, on 'Communication and language in the animal world'. On Thursday, October 12, Professor Hermann Bondi, F.R.S., will speak on 'Communicating science', and on Tuesday, October 17, Sir John Wolfenden, C.B.E., will lecture on 'Communication between the scientist and the humanist'.

Further information about the lectures and tickets, which will be issued during July, may be obtained on application to British Association Granada Lectures, Granada TV Network, Golden Square, London, W.1.

The Eidophor Television System

At Norwich this year, members of the British Association will be able to see, probably for the first time in their lives, colour television on a full-size cinema screen.

The projection equipment which makes this possible was developed in Switzerland by Professors Fischer and Baumann and by Dr. Gretener. It is now manufactured by Gretag Ltd. in Zürich, an affiliated company of C.I.B.A., the well-known Swiss chemical firm. It is through the generosity of C.I.B.A. that the equipment has been put at our disposal for use at the Norwich Meeting.

The projection equipment is called *Eidophor*, from the Greek *colour-bearer*. It differs from other projectors in that it does not use a conventional cathode-ray tube for picture presentation. Instead it employs a form of 'light-valve' which passes or stops light from a xenon arc-lamp in accordance with picture requirements. This technique provides adequate illumination for a cinema screen in colour.

The light-valve consists of a 'schlieren' optical system inside which light is reflected off a concave mirror on which a thin oil film is spread. The optics are such that if the oil film is not distorted no light passes through the system and the screen remains dark. The oil film is scanned by an electron beam from a conventional electron-gun and the usual television raster is produced on it. By making the plate on which the film is formed slightly positive, the film is distorted by the electron beam because the negative electrons are attracted towards the positive back-plate. The degree of distortion is proportional to the modulation of the electron beam, that is to the brightness of the picture.

This is the simple principle of the system—the complications are in its execution. For example, the oil film has to be constantly renewed, its viscosity held within close limits, necessitating thermostatic control of the unit and, of course, the entire system operates *in vacuo*.

The colour is produced by a frame-sequential method, using a three-colour disk rotating in front of camera and projector with suitable synchronising devices. The projector will also operate in monochrome, either from a closed circuit source or from broadcast transmissions.

The unit to be employed at Norwich, will be brought from Switzerland in its entirety; it consists

Dr. J. B. P. Williamson

of a complete three-camera-unit with its associated control van—or 'scanner truck' as it is called—together with lighting, sound and, of course, the Eiodophor projection equipment.

The operation is thus more complex than a television Outside Broadcast. The programmes will come from an improvised studio by cable to the projector. In less favourable topographical circumstances, a radio link is used to carry the picture up to distances of several miles. Due to loss in the colour disks, the amount of light needed is some five times that required by monochrome television cameras, and it must be held at a precise 'colour temperature' otherwise colour balance suffers. Make-up poses special problems as the cameras tend to be somewhat red-sensitive and may emphasise normally invisible capillaries giving faces an unnatural ruddiness.

The system will be used to transmit scenes of the Inaugural Meeting in St. Andrew's Hall on August 30 to an overflow Meeting in the neighbouring Blackfriar's Hall. After this, there will be three programmes mounted as complete television features. These will emanate from a studio in

Blackfriar's Hall and be projected to an audience of 1700 in St. Andrew's Hall. The first programme will feature Prof. C. D. Darlington, F.R.S., and will deal with a biological subject. The second, featuring Prof. S. Tolansky, F.R.S., and Dr. A. H. Traber will include demonstrations of microscopy and of interferometry while the third, featuring Mr. Kenneth Adams will study perception through the use of optical illusions. After each programme, members of the audience will be able to ask questions of the expositors and have them answered over the television link. All the programmes will be introduced by Arthur Garratt and produced by George Noordhof.

The Eidophor system has obvious uses for education. The large-screen and colour remove some of the limitations of conventional television while maintaining the advantages of close-ups and of the immediacy and intimacy unique to the medium. The programmes at Norwich are planned to show those interested some of the educational possibilities of the system as well as permitting them to see and hear expositions by leading scientists using some of the resources of modern science as a communicating medium.

AREA COMMITTEES

New Area Committees

Two new Area Committees have been established, one at Cardiff, and the other for North-East Essex and East Suffolk.

The Cardiff Committee is a direct outcome of the Annual Meeting last year. It was considered unfair to ask for an Area Committee to be started while everyone was working at full pressure for the Annual Meeting, but as soon as everyone had recovered from the Annual Meeting things moved fast.

In March the Lord Mayor, Alderman Mrs. M. Dorothy Lewis, called a meeting at which Sir George Thomson represented the British Association. A resolution recommending the appointment of an Area Committee was passed, the Lord Mayor pledging herself and her successors in office to serve as President, with Prof. W. R. D. Jones as Chairman, Dr. E. Sheppard as Secretary, and Mr. R. L. Davies as Treasurer. The Local Committee for the Annual Meeting decided that the residue of the local fund should be made over to the Area Committee for the development of their work. The prospects for an active and enthusiastic committee are excellent.

In April the project for a Committee in the southern part of East Anglia came to fruition, with the establishment of the North-East Essex and East Suffolk Committee. The Earl of Cranbrook (President of Section X for Norwich) has consented to act as Chairman, with Dr. A. D. Merriman (Chairman of the Science Council of Ipswich City College) as Vice-Chairman and Dr. C. O. Stephens (Principal of the North-East Essex Technical College, Colchester) as Secretary. Section L is well represented on the Committee through Mr. L. R. Missen, C.M.G. (Chief Education Officer, East Sussex, and Past President of the Section) and Dr. B. E. Lawrence, C.B.E. (Chief Education Officer, Essex, and President of the Section for Norwich).

Area Committee Lecture Programmes

The final figures for Area Committee Lecture Programmes from April 1960 to March 1961 are now available. They show that the following number of lectures were given by the busiest committees:

West Midlands	188	lectures
Tees-side	183	„
Newcastle	127	„
Durham	120	„
West Riding	86	„

With other Committees providing solid if less prolific programmes (Northern Ireland, Aberdeen, Tayside, Glasgow and Cornwall in particular), the total number of lectures given by Area committees during the year was not less than 800, and total audiences must have been in the neighbourhood of 40,000.

Junior British Association Meetings

From April 25 to 28 the West Midlands Area Committee presented their second Junior British Association meeting. As last year, it was designed to cater for 4000 young people over the four days, with each participant hearing two lectures and a film programme, and having the opportunity to see a number of exhibits. With last year's most successful meeting as the basis for planning, this year's meeting was a very smooth and efficient performance.

On the first day the Lord Mayor, Alderman Garnet B. Boughton, gave civic recognition to the

meeting by welcoming those attending on that day, in an opening ceremony which was also addressed by the President, Sir Wilfrid Le Gros Clarke, and the Vice-Chancellor, Sir Robert Aitken. At the end of the ceremony the 1000 participants were led away to their lectures, in complete order and with good speed, by the stewards.

The programme of lectures was of a very high standard, the speakers being:

On 25 April, Prof. Dame Kathleen Lonsdale (Facts, Aims and Values), Prof. A Charlesby (Beneficial Effects of Atomic Radiation), Prof. C. L. Wilson (What, and How Much?), Mr. T. A. L. Paton (The Kariba Dam) and Dr. J. D. Carthy (Animal Sounds).

On April 26, Prof. A Charlesby, Prof. C. L. Wilson and Dr. J. D. Carthy again, with Mr. J. T. Allanson (Listening to Sounds) and Mr. D. E. Broadbent (On Making Up Your Mind).

On April 27, Dr. H. B. Griffiths (A Look at Pure Mathematics), Prof. E. F. Gale (The Bacterial Cell), Dr. M. P. Reece (The Physical Principles of Switches and Circuit Breakers), Mr. B. B. Lloyd (The Breath of Life), and Sir Raymond Priestley (Antarctic Exploration Yesterday and Today).

On April 28, Mr. W. J. Slater (Spin and Swerve of Balls), Prof. M. Stacey (Chemical Studies on Some Naturally Occurring Giant Molecules), Prof. A. D. McQuillan (The Science of Metals), Prof. J. Heslop-Harrison (The Molecule and the Cell) and Mr. Patrick Moore (Rockets into Space).

On all four days three films were shown, 'Outline of Detergency', 'Unseen Enemies' and 'Glass', seen by all the participants. In addition, there were a number of exhibits, provided by university departments, industry and societies, in the Great Hall.

The organisation was immaculate, and there was not a single hitch in the four days. Representatives from Newcastle and Sheffield (for reasons which will be clear) were present at the meeting; and they enjoyed it as much as everyone else.

The Sheffield Area Committee are well ahead with their plans for the Junior British Association Meeting from July 20 to 25. Once again a variation is being introduced. They conceive the meeting as being two two-day programmes, with the same audiences (about 600 in each case) attending on the Thursday and Friday in one case, and the Monday and Tuesday in the other. Each participant will therefore hear four lectures and see two film shows, and the programme for each of the two halves will be the same. Each audience will be divided into three sections, for advanced level science sixth, for ordinary science sixth, and for others, with lectures selected for each section for subject matter and content. The only difficulty with this scheme is that of the more distant school parties getting in for two successive days. It will be interesting to observe the working of the scheme.

Another Junior British Association meeting is planned for Newcastle, with the generous support of the King's College academic board, to take place early in April 1962. This meeting is being organised on lines similar to those followed at Birmingham, and it is hoped that a considerable proportion of the sixth forms of the area will attend the meeting.

Science Fairs

Following the Manchester Science Fair, fully reported in the last issue, the Tees-side Area Committee will be arranging a Science Fair at Middlesbrough in January 1962. This will again be supported by *The Sunday Times*, and the Committee have already been in close touch with the *Middlesbrough Evening Gazette*, and have appointed as Manager for the Fair, Mr. Arnold Ellis.

The West Riding Area Committee are planning a Science Fair for the spring of 1962, and have been in touch with Mr. D. Avison, who is Chairman of the Manchester Federation of Scientific Societies and was most closely connected with Manchester Fair, but who lives in the area of the West Riding Committee.

Conference on Science in the Primary School

On September 29 and 30, (a convenient interval after the Annual Meeting) the Association will in collaboration with the Association of Teachers in Colleges and Departments of Education hold a conference in London on approaches to science in the primary school. Papers on this subject have been read at recent Annual Meetings, and much excellent work has been done in many parts of the country. It is felt that the time is now ripe for a conference to try to state the principles which should be followed in this work, and in particular what must not be done and what can and should be done—and what can and should be taught to

trainees in Training Colleges who are going to teach in primary schools, but have very little scientific background. Further information about this conference will be given in the next issue.

Lecture Service

On the invitation of the British Association Young People's Scientific Society, Aberdeen, Sir Lawrence Bragg visited Aberdeen and fulfilled a strenuous programme, lecturing on 'Magnetism' to three school audiences and on 'Proteins' to a large gathering at the University. The lectures were illustrated by very fine demonstrations and experiments. Queen's College Dundee, had Dr. T. W. Wormell to speak on 'The physics of thunderstorms'.

At other lectures sponsored by museums, colleges and scientific societies for school audiences, Derek Searle spoke at the City Museum, Newport, on 'Antarctic Expeditions' and Patrick Moore at the City Museum, Bristol, on 'Exploring the moon' and Dr. Magnus Pyke on 'Science, food and eating' at the City College and Art School, Norwich. The Astronomer Royal, Dr. Van der Riet Woolley, spoke to the sixth forms of schools in the Brighton and Hove area. Dr. T. R. Kaiser gave the I.C.I. Alkali Division Easter Lecture for children on 'Physics in the Antarctic'.

As usual, many lectures have been arranged for individual schools and for school science societies, an outstanding series being those given at Bristol Grammar School to the sixth form of over 300 pupils comprising both Arts and Science groups.

An integral part of the work of the Lecture Service is concerned with Training Colleges, and there is a marked increase in the requests coming from Teachers' Associations for speakers on science at annual conferences and at regional conferences. Prof. O. R. Frisch, F.R.S., gave the inaugural talk at a recent meeting of science teachers of Hertfordshire. At the request of the East Sussex Education Authority, the programme for a course on 'Living and learning in a scientific age' was arranged for a residential conference of East Sussex teachers. At this very successful course, Dr. W. E. Swinton gave the general introduction, Mr. Nathan Isaacs spoke on 'Science in Primary Schools', Prof. H. C. Dent on 'Science in Secondary Modern Schools', Dr. M. Bassey on 'Science in Grammar Schools'. These talks were followed by a symposium on science teaching by Heads of Departments in Secondary Schools. There was a session on the use of visual aids, taken by Mr. A. M. Hughes, and finally Mr. A. Newth gave a talk on 'Teaching physics in school and the university'.

A lecture on nuclear energy by Prof. J. Rotblat and one on communications in space by Mr. F. E. J. Girling was given at the Senior Army Officers' Course at Moor Park College.

Professional audiences and technical staffs, foremen and supervisors of industries are making increasing use of the the Lecture Service for talks on subjects, usually of particular technical interest to the groups concerned.

Many lectures have been arranged for scientific societies such as the Worthing Science Society, and the newly formed Guildford Society for the Advancement of Science; also for Rotary Clubs, Round Tables, W.E.A., and other organisations.

In March, for the first time at a residential course held by the National Federation of Women's Institutes at Denman College, a full programme of lectures was arranged on atomic energy and automation. Prof. Rotblat, Dr. Patricia Lindop and Mr. R. M. Longstaff, were the speakers on the first two days. Prof. Rotblat in his address, considered the principles of fission and fusion and the use of atomic energy and some of its social and international implications. Dr. Lindop spoke on the question of radiation hazards and the uses of radioisotopes in medicine, and Mr. Longstaff on the industrial applications of nuclear energy and radioactivity. On the final day there were lectures by Dr. A. D. Booth on Computers, and as a climax to the course, a Brains Trust with Prof. Rotblat, Dr. Lindop, Dr. Booth and Mr. Welford forming the panel. The programme was most enthusiastically received. The members taking part were county representatives from many parts of the country and it is hoped that their interest will stimulate further interest throughout the Federation, and create a demand for lectures at County Federation and Group Meetings.

ADVANCES IN TREATMENT BY PSYCHOTROPIC SUBSTANCES

By E. BERESFORD DAVIES, M.D., D.P.M.

Mental pain is traditionally man's worst affliction, and attempts have been made for scores of centuries to alleviate it. It is in the setting of this statement that I would like to lead up to the subject of psychic energisers. One of the most successful substances, discovered long ago and still widely used, is ethyl alcohol, the taste of which oddly enough has to be disguised in some suitable liquid. Other substances employed for the same purposes include the alkaloids, usually extracted from vegetable sources though sometimes synthesised, and those of a heterogeneous group too numerous to detail, such as bromide, chloral, organic halogen compounds, paraldehyde, and of course the widely used barbiturates.

All these substances, with their undoubted uses, possess certain disadvantages. These disadvantages may be divided into two kinds; first, those called side-effects: and second, those called toxic effects. Thus alcohol, which is taken mainly on account of its capacity to produce a feeling of well-being, may cause drunkenness as a side-effect. On the other hand neuritis or cirrhosis of the liver are what we call toxic effects. In some cases the distinction between side-effects and toxicity is more convenient than real, for the kind of trouble produced by a drug is often determined by its concentration and the length of time for which it acts.

Now all these substances have actions throughout the body, including naturally the nervous system itself, and most of those I have mentioned have direct effects, apart from their general nervous action, upon the highest centres of psychic organisation, and it seems clear that they act by a process of selective paralysis in which the most sensitive and recently acquired abilities suffer more quickly and more severely than the basic long established nervous reactions.

It may be that this phenomenon is associated—at least it is tempting to think so—with the capacity of many of these substances to become drugs of addiction. They have the power more or less to diminish unpleasant feelings such as apprehension, uncertainty, fear, and the sense of self-criticism; these feelings are replaced by a sense of potency and expanding well-being, which it should be mentioned is usually quite unrelated to the true facts of the situation. Naturally, as all things are relative, the feelings produced may be not more than a sense of relief—a blessed absence of whatever unwelcome feeling previously dominated the psyche: addiction more commonly begins as an attempt to secure such relief than as a deliberate search for new and exciting sensations. Many of these unpleasant sensations are almost indescribable, some on account of their physical complexity, and others by reason of the hierarchical structure of the psyche, in which are submerged unconscious and inchoate layers of feeling and experience. Descriptions of anxious expectation, agonised apprehension, tension with physical accompaniments such as a literally dread-full hardening in the pit of the stomach—these are all attempts to put into words what are clearly individual feelings which at best can be but imperfectly conveyed to another person. In the psychic field fearful sensations of uncertainty or imminent divorce from reality are further examples of the mental pain from which relief may be sought at all costs.

There are a few substances which stimulate rather than paralyse; examples are caffeine or amphetamine; the popularity of tea in this country and coffee in others is explained mainly by these stimulatory properties. In some persons the drinking of tea is an addiction in the true sense of

the word, though of course a fairly harmless one. These stimulatory substances are also likely to cause side-effects, the most serious of which usually appear in the psychic field. Loss of judgment, overexcitement, and severe restlessness accompany overdosage with amphetamine. Occasionally, and possibly to an increasing degree, amphetamine and its new synthetic relatives are drugs of addiction, some of which give rise to serious symptoms associated with disorder of behaviour.

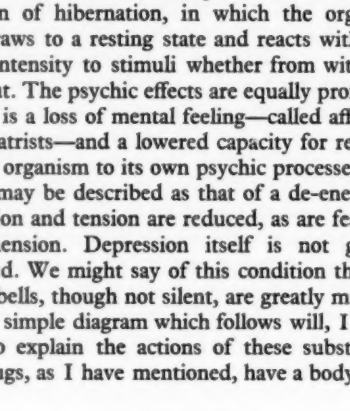
This then was the position as far as these substances were concerned until about eight years ago, when a discovery of profound importance was made. This was the synthesis of chlorpromazine, popularly called Largactil, by French workers, who were I believe looking for a means of preventing certain kinds of nervous shock, particularly after wounds or exhaustion. The substance they discovered possesses *hibernating* and *tranquillising* properties, and its mode and site of action are different from those of the psychic paralysers such as alcohol. Furthermore, chlorpromazine does not appear to cause addiction though it is certainly far from free from side-effects and occasional dangerous toxicity.

The appearance of chlorpromazine had revolutionary consequences; first as a means of treatment; second as a stimulator of pharmacological research, and third as a provoker of new thinking about the biochemistry of the central nervous system. To take the second consequence first, we see that a whole range of new substances has been developed; in fact these follow one another so quickly that even a specialist in the field has today too little time to follow all the latest developments, and he must therefore specialise within a part of this specialised field. Despite an immense amount of work we still do not know much about the basic actions of these newer substances, and we are far from achieving a clear idea of the manner in which they may intervene in the natural or pathological biochemical processes of the central nervous system. This lack of precise knowledge is reflected in the confusion which surrounds the descriptions of the drugs and their actions. In general however it seems safe enough to call these drugs which have effect on feeling or thought, psychotropic substances, and to give simple descriptive titles to them according to their chief function. Thus we may call them sedatives, tranquillisers, energisers, ataractics, or any other suitable name. We cannot avoid this purely descriptive phase in psychiatric medicine any more than it was possible to avoid it in medicine and surgery generally in the past.

Perhaps it is best at this point if I retrace my steps to the first consequence of the synthesis of chlorpromazine, namely to describe more fully this drug and the treatment made possible by it. I can then give some attention to the probable site and modes of action in the central nervous system of drugs generally.

The basic action of chlorpromazine is the production of hibernation, in which the organism withdraws to a resting state and reacts with lessened intensity to stimuli whether from within or without. The psychic effects are equally profound. There is a loss of mental feeling—called affect by psychiatrists—and a lowered capacity for reaction by the organism to its own psychic processes; this effect may be described as that of a de-energiser. Agitation and tension are reduced, as are fear and apprehension. Depression itself is not greatly changed. We might say of this condition that the alarm bells, though not silent, are greatly muted.

The simple diagram which follows will, I hope, help to explain the actions of these substances. All drugs, as I have mentioned, have a body-wide



action quite apart from their effect on the particular place which we wish to reach, so that when I stress the psychic actions I want to emphasise that these may be produced directly or indirectly—that is by some immediate pharmacological action on the cells

whose functions we are studying, or by an action upon some other part whether near or distant, with an indirect effect upon these cells.

The diagram shows (1) the cortex of the brain, which contains the higher centres and functions and all the superior psychic processes; and (2) the autonomic or automatic part of the central nervous system—this is the oldest and has to do with the most basic functions of the organism and their rhythmical co-ordination; (3) the midbrain, which I show here, is the seat of emotion and feeling, and also contains complex systems of communication; (4) here we have the pathways of ingoing and outgoing nervous impulses.

The paralysant drugs depress the whole of the nervous system but, as I have mentioned to you before, their greatest effects are upon the highest centres, and we see the blunting of the subtle functions as a first effect. Overdosage results in death from respiratory paralysis. We may take the respiratory centre as the sturdiest and most resistant to drugs of the basic automatic functions. Chlorpromazine on the other hand probably affects chiefly the midbrain and many of the psychotropic substances probably affect chiefly this same region. One piece of evidence that their action is different from the paralysant drugs is that relatively enormous doses may be taken before the whole of the nervous system becomes poisoned.

You will have heard already of the compounds called amines. These are pressor or activating substances, and are found all over the body. Certain of them are concentrated in the midbrain area of the central nervous system, and research has shown that they have chemical connections with other substances in the body and brain which we believe have to do with mental states generally. This is a very interesting situation and one still far from adequately understood, mainly I think because we have no clear idea about the regulation of the biochemistry of the region. If we look at the position in a more general psychiatric way we can see that there is within the brain—and it is my opinion that it is within the midbrain—a centre of energy which has the remarkable quality of self-modulation. This centre provides energy in a rhythmical manner, in the right quantity, at the right time, and in the right place—in other words it is a kind of self-winding physiological clock. It is therefore not altogether suprising that we find evidence of balancing actions initiated in this area. This is reflected in the effects of the promazine and similar groups of drugs in an interesting manner. Thus if we give chlorpromazine to a patient who suffers from agitated depression we may relieve part of his mental turmoil, particularly the tension or anguish. We also find that if we give the same drug to a patient in maniacal excitement it produces calm and a lessening of mental pressure. Now these two states, namely depression on the one hand and mania on the other, are opposite in character, so that we see the same drug has the effect in each case of bringing the patient back more closely to what we may call a middle line.

One substance, for whose fascinating history there is unfortunately no space, called imipramine, closely chemically related to chlorpromazine, is a very successful anti-depressant, though it often has to be combined in treatment with other drugs to control agitation. My main point in mentioning it here is to illustrate the bewildering specificity of effect of some drugs closely chemically related to others which have an obviously wide spectrum of action. It is however well worth mentioning that this drug can be successfully used in the treatment of over half our cases of endogenous depression, which represents a most notable advance, and of course encourages the pharmacologists in their search for something even better. At the present time we often have to use two, three or even more psychotropic drugs together, for we have not yet refined our methods enough to produce a drug capable of several functions at once. It is very fortunate therefore that there are few incompatibilities among these drugs.

You will have noticed that I have been speaking almost entirely about feelings, and very little about thoughts. This is because biochemical advance has somewhat naturally followed the lines of medical demand, and as I mentioned at the beginning of this paper, relief from unpleasant psychic tensions has been one of man's major objectives. It is also pertinent to observe that most of these illnesses in which emotion is disordered and which are responding to chemical treatment are those in which the main structures of mind and the thinking processes themselves are either unaffected or else only temporarily disturbed. I am of course drawing a clear distinction—which seems entirely warranted in the present state of

our knowledge—between the emotional or affective disorders on the one hand, and the great group of schizophrenic illnesses, with their profound disorder of thinking, on the other. I would like to suggest that we call these affective illnesses disorders of temperament. We may define temperament as the individual's basic mental feeling tone, from which stems his affect or emotion, and his moods which vary according to internal and external circumstances. It seems clear that most of the tranquillisers act by limiting or diminishing the available quantity of affect irrespective of the illness in which they are used. The anti-depressants such as imipramine however appear simply to remove depression. Nevertheless I cannot forbear to mention the puzzling and fascinating fact that if this anti-depressant substance, namely imipramine, is given to a patient whose illness has a schizophrenic basis, then the result may be a rapid worsening of that patient's mental condition. At the moment we do not understand this at all.

At this point, I must make a digression. Some years ago a substance called iproniazid was introduced for the treatment of tuberculosis. Among the many things discovered about the clinical action of this substance was, first that it proved very poisonous in some cases; second that it had unexpected physical actions such as the relief of cardiac pain in certain heart diseases; and third, and truly astonishingly, that it showed a most effective anti-depressant effect in certain hitherto almost intractable cases of depression.

Iproniazid is a member of the class of compounds which has the formidable name of mono-amine oxidase inhibitors, which in self-defence workers in this field have reduced to the letters M.A.O. These substances retard or stop the action of an enzyme which is found throughout the body, whose function is the oxidation or rendering useless of the amines, which as far as the nervous system is concerned you will recall are chiefly concentrated in the midbrain area. In theory therefore these substances slow down the natural destruction of amines in the central nervous system and they therefore truly merit the title of psychic energisers.

It is of course tempting to assume that this biological action is the reason for the success in the treatment of states of depression, states of anergia, and states of hypochondria by these substances but unfortunately, as always in medicine, there are snags. For example in the case of one of them, nialamide, which undoubtedly acts beneficially in certain depressives, and which undoubtedly displays in general the typical M.A.O. effect, recent work has shown that in some cases which benefited from the drug the typical M.A.O. effect was absent. It might be of course that the improvement in these particular cases was incidental and not associated with the drug.

My own view however is that the evidence suggests that in addition to the M.A.O. effects of these drugs there may well be direct or indirect pharmacological actions of a beneficial kind of which we still know nothing. A further speculation which it is interesting to make is that the midbrain may partly achieve its balancing act by the regulation of the supply and quantity of amines, one of the factors in which we may suppose is the destruction of the amines by enzymes; be this as it may there is now some scientific evidence that the midbrain has a greater claim to be the seat of the emotions than the traditional solar plexus.

And now a word or two about the clinical results of treatment by the M.A.O.s. I am sure you will all have heard of electroplexy, the well-known electrical treatment which has been used with such tremendous success over the past twenty years for the treatment of what we call endogenous depression. I have already mentioned in this paper the drug imipramine, which has also achieved an outstanding success in the treatment of endogenous depression. Nevertheless there remain an important heterogeneous group of cases of depression, many of which do not respond to electroplexy, imipramine, or any similar treatments. It is among this group that the M.A.O.s have achieved a considerable success.

Iproniazid, the first of them, despite its toxicity is still being used with considerable success in a particular group of patients. These are the patients who complain bitterly of depression, and usually of all kinds of physical and mental aches and pains which appear and disappear with bewildering rapidity. Apart from this, these patients usually show a disagreeable response to their illnesses, so that they become miseries to themselves and burdens to their nearest and dearest. Often their depressive illness is mistaken for hysteria, as

hypochondria, egotism, self-centredness, and changeable complaints, are well-marked features. Under suitable circumstances iproniazid can transform these patients into persons who are a surprise to the doctor who is treating them. They cease to complain, they produce constructive thoughts about themselves instead of perpetual criticisms, and their symptoms diminish strikingly. It was this very effectiveness of iproniazid which began the vast research into similar substances. Obviously there has been a great need for something which would be as effective clinically but would not possess toxic qualities.

It is not the place here to go into the biochemistry and pharmacology of the means whereby less toxic products are made. However, I can say that today there are almost a dozen M.A.O.s, all of which are far less toxic than iproniazid, and some of which appear very promising. We are not yet in a position to be sure about which cases will profit more from the M.A.O.s than from other treatments. Certainly we can regard the M.A.O.s as anti-depressant, but with this quality they have the capacity it seems to produce energy and activity. A dull, depressed patient who has lost his interests and found them replaced by anxieties and worries about his body or mind, and who feels that nothing about him works very well, may find on taking an M.A.O. that he rediscovers his energy, that his circumstances are less drab and more attractive, and that he has a fund of energy previously very much lacking. It is as though his attitude to his life in general had changed so that what previously he found distressing or dispiriting is now interesting and challenging. With this there appears to be a general increase in physical output, and with some of the M.A.O.s over-activity can be seen. As I am sure you will know, there are some patients who have well-marked phases of depression, alternating with excitement. It has been found that if such a patient in a depressed phase is treated with an M.A.O. there is the possibility of the production of a state of excitement, with the need therefore to withdraw the drug. To some extent this danger can be obviated by the simultaneous use of tranquillisers. Nevertheless it seems clear that one of the side-effects which may constitute a considerable drawback to drugs in this class is the production of over-activity. It is quite commonly met with in some cases in the form of sleeplessness. Some patients sleep far less than the normal, and moreover appear quite well on this régime. I think however it is necessary to have a few reservations for, however well the patient may feel, there is the danger of over-fatigue under such circumstances.

To sum up the effects, there is an increase in energy, the energy produced is put to good use, there is a lessening of depression, and there is the reintroduction of the patient into the general scheme of his or her life. This last point is very important, for it makes possible effective supportive psychotherapy whereby a psychiatrist can help the patient to make the best use of his newly regained capacities.

The use of these powerful new drugs has presented certain moral problems. First of all there is the question of their adequate clinical testing. Obviously a valuable part of the testing of a drug must be the giving of it to one portion and the withholding of it from another portion of a selected group of cases all of a similar kind. This is an old problem already dealt with in various books and plays.

I would like to digress for a moment at this point to mention an important aspect of the selection of suitable case material for drug trials. One of our great difficulties in understanding disorders of temperament, and one which incidentally has been appreciated for quite a long time, is that of collecting together case material in which we can be sure that we make successful classification. Arguments still go on about the nature of depression, for example. Is it on the one hand a biochemical disorder in the midbrain, with subsequent psychological effects? Is it on the other hand a psychological reaction to some internal or external stimulus which secondarily affects the nervous system? Or is it perhaps a mixture of both these aetiological chains of events? At first the discoveries of the biochemists complicated our clinical situation, but now I think a little clarification is just beginning. If we could put on one side for the moment the question of psychological depression produced by psychological causes, and consider instead the situation in the midbrain, then I would suggest that the classification of the disorders of temperament is less likely to come from the clinical observation of patients than it is from a better understanding of the biochemistry of this region of the central nervous system.

And now back to moral problems. To my mind a more serious difficulty arises out of the nature of the response itself to treatment of these new substances, which will probably be more serious when research has produced more specific and selective drugs. Tranquillisation produces a lessening of affect generally and it undoubtedly diminishes drive. There are some who see in this a danger that we may become a nation of Lotus eaters. Apart from this the lessening of the pangs of conscience and the emphasis on the enjoyments of the pleasures of the vegetative nervous system are viewed askance by certain moralists.

The anti-depressant and energising drugs also bring problems. Some argue that depression is appropriate to certain circumstances in life and that to remove it is wrong. A more serious criticism than this may be made, in my opinion, about the use of the energising drugs, some of which have a euphoriant action. In promoting a sense of well-being as against a feeling of depression they sometimes appear to cause a swing-over to a frame of mind already familiar to us in patients with states of excitement, or those who have had certain brain operations or injuries. Mr. Toad, in *The Wind in the Willows*, when he was not in a state of unloved misery, used to throw his weight about intolerantly and egotistically as he followed his latest craze. In these patients sensitivity and sensibility are reduced in a setting of mental alertness. Thus such people may be socially over-active or interfering, and they are often tactless, intolerant or thoughtless. I have known several patients treated by an M.A.O. who have had the insight to remark upon the change in themselves. One lady, an active committee woman, said 'I feel more outspoken—I hope I shan't give cause for offence'. Undoubtedly with the sense of well-being that accompanies successful treatment by several of the M.A.O.s there is a tendency to mild hypomania—in other words a little mania—and this shows itself in the classical trilogy of characteristics, namely excitement, psychomotor activity, and pressure of thought. There is therefore some risk that the improvement in the patient's condition may be achieved at the expense of his environment, and occasionally one is forced to consider whether it is right to improve the patient while emphasising in him less desirable qualities. Should Mr. Hyde be allowed by the use of a drug to peep over the shoulder of Dr. Jekyll?

The development of biochemical means of treatment may thus lead to a much more effective control of those diseases which appear to be due to disorders of temperament. States of depression, excitement, tension and agitation, as well as much less easily defined disorders in which the autonomic system is involved, or where psychosomatic and glandular dysfunction occurs, all fall within this range. I have already tried to show you how the prevailing mood may influence facets of character and personality by emphasising certain of their attributes. However, I think we must draw the line somewhere at the present time as far as biochemical influence upon personality and character is concerned. The place where I would draw this line is where we find basic psychological traits in any individual which, though they may be diminished or exaggerated by the influence of drugs or temperamental changes, do not seem to alter in their nature and quality. It is perhaps easiest to give an example in order to convey my meaning. If a person is of, say, a suspicious nature—that is to say always looking for some explanation of natural events or the conduct of others which he bases upon hidden motives, in technical language he has a paranoid mind, then it is likely that notwithstanding his mood, his tendency to such suspicions will always exist. Expansive moods and those of general well-being may help such a person to overlook his suspicions, but they are still likely to be present. At this moment it does not seem probable that we shall find specific drugs which are capable of making a suspicious mind into a generous and trusting one. It seems much more likely that such psychological traits as this are developed within the psyche as a result of pressures and forces acting over many years in soil favourable to their growth. One can think that the same mental physico-chemical flux might support a good thought or a bad thought equally well, and that the goodness or badness of the thought is determined, not by the biochemical nature of the field in which it exists, but by something entirely different.

Clearly this is of the utmost importance, for it suggests that though we should by no means reduce our researches into temperament, we must also try to understand much more successfully than we

have in the past, the nature of psychological processes and their connections with the physicochemical world which we are just beginning to chart. Thus in the future we have the paradox that the more we shall know of the biochemical nature of the brain, the greater will be our need to understand the psychological nature of the mind.

Now what of the future? As a psychiatrist I am bound to say that I am far less troubled by the objections just referred to, many of which appear to me theoretical rather than real, than I am worried by the evident mental pain of my patients, many of whom have temporarily or permanently lost the battle of their feelings. In such cases a doctor cannot heed the Jeremiah's warnings that with the tranquillisers there is a danger that man will amble along wasting his time in pheasant befuddlement, or with the psychic energisers that he will become a mere spinning top, a nuisance to himself and a danger to others. Psychiatric medicine is in a stage of fascinating and often bewildering expansion. This time the leap forward is not basically psychological, as it was with Freud's discoveries, but is biological and biochemical. Quite apart from the intrinsic importance of this process it has the immense value of linking psychiatry with general medicine and the biological sciences, which will help ensure a respectability and stability for psychiatry which it might never achieve through purely psychological research and knowledge.

I suggest that the lesson is plain. We have just made a step forward with the discoveries of the past eight years since the synthesis of chlorpromazine. As usual we know too little about the meaning of what we are doing. We stumble accidentally on our findings, and inevitably as clinicians we meet serious risks and we cannot be sure of the consequences of what we are doing. This therefore, since to try to put the clock back is unthinkable, is the time for more research, better drugs, and above all more trained men so that we may continue to relieve mental suffering with ever increasing discernment and discrimination.

SCIENCE IN THE SIXTIES*

By Dr. ALAN T. WATERMAN *Director, National Science Foundation, U.S.A.*

In his work on the history of western thought, Crane Brinton comments on the impetus given by artisans to the rise of modern science. Historically it was technology that came first and supplied the tools and instruments that played a part in the rise of experimental science. Science arose when man began to extend his thinking beyond immediate practical effects, especially into the regions of generalisations and abstractions. The interaction of technology and science has been a continuing process in the last three centuries, and each plays a role in the spectacular progress made by the other. The last two decades have witnessed a remarkable acceleration in both areas, stimulated initially by wartime developments and carried rapidly forward by their own momentum.

This same period has also witnessed radical changes in the composition of what might be called the research community as well as in the reasons for which research is done.

Until about the beginning of the present century, research was largely confined to the university, where it was associated purely with teaching and the advancement of knowledge. Then industry began to see the advantage of creating its own research laboratories which would provide fundamental knowledge for the furtherance of its products. And finally, with the advent of World War II, the Federal Government became an active participant in research and development by expanding its own laboratories, but more notably through widespread contracts with universities.

The increase in the diversity of the research community has been accompanied by new motivations for the performance of research and development. To the desire to advance knowledge and to make fundamental discoveries of potential economic value have been added the large-scale research efforts directed toward the conquest of disease and to the national defence.

The growth in the number of groups performing research and development and in the reasons for doing so have combined to bring about great increases in the sums available for research and development, which this past year have reached an estimated national total of $12·5 billion, to which another billion will be added in 1961.

Superimposed upon these circumstances we have an international political scene that engenders an intensely competitive situation with respect to science and technology. Thus we stand at the threshold of a decade dominated by science as no other era has been except, perhaps, the seventeenth century, when the impact of science caused John Donne to exclaim, 'And new philosophy calls all in doubt'. With what opportunities and what problems does this situation present us?

It is, of course, impossible to predict discoveries that may lie ahead in science, but the knowledge that we have acquired in recent years, coupled with a whole array of spectacular new instrumentation, insures that important break-throughs will occur in a number of significant fields. Starting with the macrocosm and working our way through the gross phenomena of our universe and our environment to the subatomic world of nuclei and particles, we see that we are acquiring new knowledge at an ever-accelerating pace. New tools and techniques are giving us new insights and the old hard and fast classifications of knowledge into separate disciplines are gradually giving way as piece after piece falls into place in what seems to be the grand symmetry of nature.

In astronomy the development of image amplifiers and radio telescopes has enabled us to acquire new knowledge of distant galaxies as well as of our own. On the basis of work that is now

* Address given to the Scientific Research Society of America and reprinted by courtesy of *American Scientist*, March, 1961.

being done, there is reason to hope that, within the next five years, astronomers will be able to place a telescope of the order of 36 inches into orbit, and within ten years, perhaps, one of 50 inches or larger. On a somewhat longer time scale, astronomers are planning how to put a radio telescope in space far beyond the radio interference being generated on an ever-increasing scale both on the earth and by man-made satellites. As we escape from the obscuring factors in the earth's atmosphere, it is highly probable that the next decade will provide many new data that will help us to decide between alternative theories of the creation of the universe. Space research is also certain to shed novel light on the nature of life itself, particularly if we are able to bring back samples of living systems, say from some planet.

The highly successful International Geophysical Year, during which a vast accumulation of synoptic data was acquired, has added to our knowledge of the atmospheric sciences as well as calling attention to gaps in our knowledge in such important fields as oceanography and seismology. The natural phenomena associated with these fields are so complex that in the past we have been unable to do much about them. Now the availability of the weather satellites and high-speed computers makes it possible to handle these problems. It was Von Neumann's vision that the circulation of the atmosphere could be made amenable to calculations by means of the computer.

The construction of new oceanographic research vessels equipped with the latest instrumentation is the beginning of a massive attack on problems of both physical and biological oceanography.

The conclusion of the Antarctic Treaty, which makes this special portion of the earth's surface in effect a scientific research laboratory, is a triumph for international relations as well as for science; it demonstrates that science is an effective force for co-operation and good will among nations. In the post-IGY period, studies have been expanded to include, in addition to the acquisition of synoptic data, individual research projects in fields not included in the IGY: biology, geology, and cartography. Within the next ten years the overall mapping of the Antarctic should be completed and we shall undoubtedly learn the shape and nature of the continent under the ice. We shall know whether the snow and ice are increasing or decreasing, and we shall progress in understanding the heat and water budget of the Antarctic. We should have a good delineation of atmospheric problems and those relating to the earth's magnetic field as a result of international studies in both polar regions but especially the Antarctic. Biologists are finding many new kinds and varieties of life in the Antarctic, especially bacteria and single-cell creatures. In fact, they are stepping back a century to do basic taxonomy and ecology in relation to these new creatures. Finally, we shall probably know what practical use, if any, can be made of the Antarctic.

In the life sciences, we find that we are able to analyse the problems in a way that would not have been possible a generation ago. Such techniques as chromatography and the use of the ultracentrifuge, electron microscope, and so on, have made it possible to apply to living matter, more quantitative measurement. At the point where men acquired the ability to isolate and manipulate the giant molecules, whole new worlds of biological research were opened up and molecular biology came into being. The chemists, physicists, and even the mathematicians began to find problems in the life sciences interesting, and the application of techniques from these disciplines has revealed new avenues of exploration. We are learning a great deal about such basic questions as how life is formed, how energy is used and stored, and how an organism duplicates itself. Pauling's work with sickle cell anaemia disclosed the link between molecular variations and certain types of disease. Fundamental knowledge of this type brings us much closer to the control of certain diseases. It is of interest to note, I think, that the Sloan Kettering Institute recently announced that it is shifting its emphasis to very basic studies in molecular biology in the effort to discover the underlying causes of cancer.

At the atomic and subatomic levels at which the physicists work, our recently acquired ability to achieve super energies makes possible more intensive search for information concerning elementary particles and the laws of force at extremely small distances. Because of the success of the Brookhaven and CERN accelerators, now operating around 33 billion electron volts, physicists have become optimistic about the possibility of achieving several hundred billion electron volts.

Another aspect of nuclear physics which is attracting great interest at the present time is what is coming to be called 'neutrino physics'. The neutrino is, as you know, the smallest known particle. It has no charge, so it penetrates matter very readily. It was originally postulated to satisfy the conservation of momentum in nuclear reactions and, later, its existence was confirmed experimentally. Nuclear reactors constitute the most copious source of neutrinos and an international race is on to study them. Physicists suspect there may be two kinds of neutrinos, and this is a subject of considerable interest. Among the questions which physicists would like to have answered is whether the neutrinos that come from nuclear reactors are identical with neutrinos associated with cosmic rays and those found in accelerator experiments.

Another trend in physics is the rebirth of interest in atomic physics, stimulated by the modern availability of mesons—the 'heavy' electrons produced in accelerator reaction and by cosmic rays. These are now available in such abundance that experiments are being performed in which mesons may be substituted for ordinary electrons. This new tool permits a whole new study of energy levels in the atom. It may be some years before the full significance of such research becomes evident.

Still another area in which there is great interest is the field of microminiaturisation. Ever since it was observed that biological organisms perform certain functions much more efficiently than machines, and in a very much smaller space, scientists have been interested in the laws of similitude. It has been found useful to test those laws by examining things that are very large or very small. Studies of solid-state physics, which produced the transistor and gave such impetus to miniaturisation, now makes it potentially possible to design materials which will allow the construction of whole instruments in a speck of matter. This process, which is also known as molecular or crystal engineering, has almost limitless applications. Many of you will recall that a year ago Dr. Richard Feynman offered $1000 to the first man who would make an operating electric motor, to be controlled from the outside, that would not exceed a $\frac{1}{64}$ inch cube in volume, not counting the lead-in wires. Last month a young engineer collected the prize for constructing a motor $\frac{6}{1000}$ of an inch in diameter. This novel occurrence suggests the rate at which the techniques of science are advancing.

As one progresses from the physical sciences through the life sciences and the social sciences, there is an ascending order of difficulty in the problems to be solved. The great progress made by the physical sciences is undoubtedly due to the fact that its problems are simpler and more amenable to laboratory experimentation. In the life sciences the problems are much more difficult; but as we have noted, these are gradually yielding to new methods and instruments, many of which have been supplied by the physical sciences.

It is in the social sciences where we find the problems which are least susceptible to laboratory experimentation. However, the advent of the computer now makes possible an approach to the permutations and combinations that abound in social situations. The computer makes possible the construction of much more complex models than have hitherto been available. By a combination of the survey and computer simulation of social processes, scientists have a technique which can in effect perform some experiments in such complex fields as economics, sociology, and human-problem solving.

I should like to note in passing that the National Science Board has recently taken action to accord the Foundation's Office of Social Sciences the status of a full division, coequal with the Division of Biological and Medical Sciences and the Division of Mathematical, Physical, and Engineering Sciences. This action reflects not only our conviction of the importance of the social sciences but our faith in their increasing ability to apply scientific methods to the solution of some of the most pressing issues of our time.

The post-war period will undoubtedly be remembered, among other things, as a period in which the trend toward bringing together a variety of specialists to work on problems of common interest received great impetus. One of the interesting developments arising out of this trend is the Centre for Communication Sciences at M.I.T. The Centre brings together electrical engineers, mathematicians, neurophysiologists, linguists, and others to study the complex phenomena associated with information-generating and

processing systems. This new activity, which is actually a combination of related activities, has important implications for a number of fields ranging all the way from the design and construction of devices for the transmission of signals by various media to neurophysiology and experimental psychology.

As one reviews the current status of science even casually, it is quite apparent that each field, as well as the convergent fields where two or more disciplines come together, offers exciting promise for the future. One is tempted to dwell on this aspect of the matter, for it is pleasant to contemplate the pursuit of truth divorced from the pressures that crowd upon us from every side. The realities of today's world are such, however, that we find we are not free to devote all our intellectual and material resources to the pursuit of knowledge for its own sake, nor even to the pursuit of knowledge for the simple motive of improving our industrial capacity.

At the present time, about 53 per cent of our total research and development expenditures is oriented toward national security. Included are expenditures by the Department of Defence, and the Atomic Energy Commission. Over the past decade the Department of Defence alone has accounted for an average of 75 per cent of the total Federal obligations for research and development. Thus when we analyse the greatly augmented funds that have become available for research and development in recent years, we find that actually only about 8 per cent is going for the very basic kind of studies that I have touched on briefly in these remarks. Breaking these down still further, we find that part of the funds for basic research are earmarked for activities related to specific missions or objectives, so that in the final analysis only a small proportion of our overall expenditures goes for research at the very frontiers of science.

At the moment there seems to be no way out of our present dilemma. The long stalemate on world disarmament gives little reason to hope that we can relax our efforts in defence research in the foreseeable future. It is sometimes said that the solution should come from the social sciences. My own view is that although the study of sociology should be encouraged and supported, research in this highly complex field is hardly likely to come up with practical answers as rapidly as they are needed. Indeed, no single discipline will do this; but all disciplines are potentially able to contribute. The whole history of science demonstrates that the solution of a perplexing problem quite often comes from a totally unexpected source; and oftener still, a discovery in one field turns out to have far greater significance in another, just as Roentgen's discovery has so profoundly influenced the course of modern medicine.

We have already seen that the application of the physical sciences, in the development of the computer to its present high level of performance, has contributed an important tool which enables the social sciences to reduce some of their complex problems to more manageable proportions.

The war saw the development of operations research into a novel technique important in the study of complex operational problems. This technique brought together such differing specialists as mathematicians, physicists, chemists, economists and biologists. In a similar but more conventional manner, emphasising the role of the engineer, systems analysis has shown its great value in development and production planning. Thus science is taking important steps in solving some of the technological difficulties it creates.

Whether our present goal is to develop national strength or to help solve some of the fundamental environmental problems facing mankind, it seems abundantly clear that our safest and most rewarding course is to encourage and support basic research as fully as possible over the entire spectrum of knowledge. It is only in this way that we can uncover the full potentialities of science and increase the probability of completely new and revolutionary findings. Furthermore, this approach is most feasible and most effective in a free society like ours. If we do this we should simultaneously concentrate upon (1) the study of basic research findings for possible useful applications; (2) the feasibility of such items for development and their relation to priority goals; (3) careful selection of those items for development and production that will help attain our goals and which we can afford—in money and effort—to undertake.

If one were to consider the progress of science and technology from the standpoint of fundamental physical laws, there are interesting parallels. The first law of thermodynamics surely applies. No energy is lost; sound research endures

and is never without value—even research devoted to military ends. Of course, the process is not 100 per cent efficient—there is friction and waste motion, resulting in heat and sound, and occasionally light! Which reminds us that the second law of thermodynamics also applies: what we are really doing is trying to decrease the entropy of the system. Organised science represents potential, available energy or power. Obtaining local decrease in entropy requires the expenditure of energy, and the process is far from being an efficient one, even in purely physical systems. While on the subject, we should perhaps remind ourselves that, in so far as we know, the over-all change in entropy must be an increase.

To conclude on a serious note: all nations are convinced that their future is bound up closely with their progress and capability in science and technology. Among modern nations this capability is becoming general. Grim competition has developed along both military and economic lines. Into this scene there enters a host of emerging nations, small and large, impatient to acquire the standards of living and the independence associated with science and technology. To solve these two major problems and maintain any kind of equilibrium will require the utmost of all participants.

As if this were not enough, science is now bringing in discoveries of graver and graver social significance. This trend is bound to continue and indeed to accelerate. To paraphrase a familiar expression: we have hardly seen anything this far! Whether future developments take the form of stupendous power over nature's resources, of influence and control over life or over men's minds, or of traffic with our sister planets, they will in all probability raise problems of such concern to the human race that mankind must—repeat *must*—learn to co-operate in their solution.

As scientists, then, while keeping ourselves available for the aspects of science important to the protection of our country and our allies, we should seek every opportunity to encourage co-operation and collaboration among the peoples of the world in the pursuit of science, maintaining its characteristic freedom from international tensions.

TECHNICAL DEVELOPMENT OF A NEW PRODUCT—POLYTHENE

By Dr. E. HUNTER *Research Department, Alkali Division, I.C.I. Ltd.*

Polythene, discovered in an I.C.I. laboratory in 1933, is a high polymer of ethylene, composed of very long paraffinic molecular chains which give it useful properties as a thermoplastic, so much so that world consumption is now over half a million tons a year.

It was found unexpectedly during a programme of work to study the effect of very high pressures on chemical reactivity. It was a discovery, not an invention with a use waiting for it, since at that time I.C.I. had no major interest in using ethylene or in the uses eventually found for polythene, and it was not very easy to decide where the product could be valuable in technology. It has been said that up to the time when it was concluded that polythene was worth development because of its flexibility, chemical resistance and good dielectric properties, the story shows that since the true importance of a chance discovery may lie outside the field of immediate interest to those who make it, effective recognition of a discovery is more likely if the researcher has a wide knowledge of science and its application in industry so that he can collaborate with others in widely different fields of academic and applied research.[1]

The development from 1936 when plans were made for semi-technical plant to the middle war years when full-scale manufacture was established was the work of chemists, physicists and engineers, many of them with no experience outside research work. The methods they evolved are now used in plants in many countries and are the basis of a very large part of the world's production. In large measure, success came from a collaboration in which it was again realised that if a specialist is to put his knowledge to the greatest use, he must interest himself in other sciences and technologies.

The development set out to make larger quantities

Solvent-spun polythene fibre, made in 1938.

250-atmosphere oil-lubricated compressor used in the semi-technical plant.

of polythene for trials in use; to fix upon a process which could be used for economic full-scale manufacture, and to assist in finding how users could best process the product, but it was faced with problems which could not be answered from existing knowledge and practice.

The polythene process can be described as simply compressing ethylene of suitable composition to pressures between 1000 and 2000 atmospheres, bringing it to reaction temperature—in the neighbourhood of 200° C.—and then separating the product, but there were unusual circumstances; the raw material was a gas, exceptionally pure by industrial standards, the pressure was far higher than in other chemical processes, the reaction was explosively unstable, and the product did not behave in the users' fabricating machinery in just the same way as existing thermoplastics.

The collaborations which overcame these difficulties involved not only those concerned with manufacture, but also technologists speaking for the users. The chemist's part was at times a major one and at times a minor one, but seldom one of isolation. He had not merely to advise from his knowledge, extended by experiment where data were lacking, but also to be active in deciding what new data would be of most help in enabling sounder judgments of important problems, and in making others aware of the minimum chemical requirements of the process. In collaboration with engineers his fundamental knowledge of physics and chemistry aided surer design, for he could help to check that the principles of the proposed design methods were applicable to the novel circumstances of the polythene reaction.

These points are illustrated by the following examples of some of the major difficulties encountered in the development.

Ethylene

Ethylene had at first been bought in cylinders, but larger quantities had to be made on the spot. It seemed a tiresome necessity to design and build an ethylene plant to study polythene manufacture but it fortunately compelled the chemist to give early attention to the unusual standards of purity required and to the economic and technical problems facing full-scale manufacture, including the question of the cheapest source.

The semi-technical plant adopted a well-established industrial process in which ethyl alcohol is dehydrated on passing through heated tubes containing coke impregnated with phosphoric acid. It was necessary to modify this process however to obtain ethylene with sufficiently low concentrations of aldehyde, ether, hydrogen and carbon monoxide—all very undesirable impurities. Laboratory studies showed how the impurities could be minimized by proper choice of reaction conditions and by scrubbing the gas with thoroughly de-aerated water. A process for the chemical removal of oxygen in a scrubbing tower was examined, but in the end, rather than attempt to remove oxygen from the product gas, it was found simpler to keep it down to a few parts per million by taking very stringent precautions to prevent its ever entering any part of the system. This required many improvements in the design and construction of gas mains, pipe-joints, valves and gas-storage.

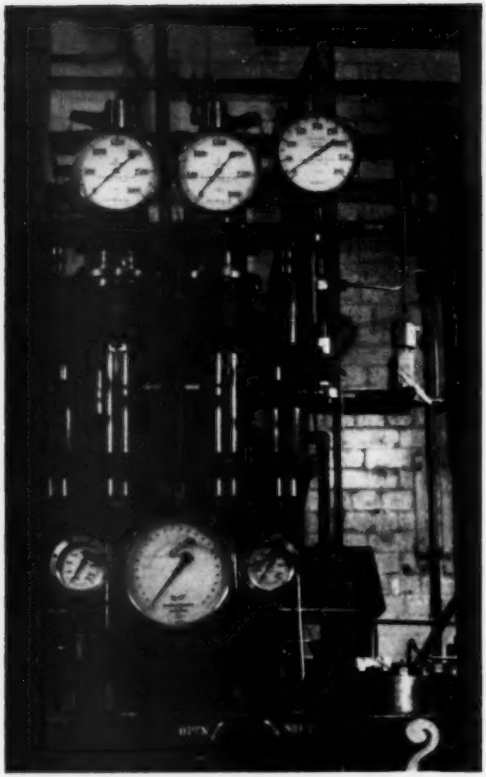
Petroleum seemed a more attractive source, even before the war, but it had then been concluded that it could only be more economic on a scale of very many thousands of tons a year, which at that time seemed an unlikely prospect for polythene. An American sample derived from oil was tested in the laboratory polythene reactor but was found useless because of quite small amounts of acetylene impurity. Extraction of ethylene from coke-oven gas was considered, but no large enough single source was available. After the war the study of petroleum as a raw material was resumed and led to the Wilton olefines plant which started to supply ethylene for polythene manufacture in 1951.

High-pressure Equipment

Equipment for 2000 atmospheres was wanted when the highest pressure process in Britain was synthetic ammonia at 250 atmospheres. Standard 250 atm. machinery could be used in a primary stage of gas compression but specially made equipment was needed for higher pressures. Even the primary compression caused difficulty, for it was found that highly-compressed ethylene dissolves ordinary lubricating oil. Water-lubricated compressors were obtained, but ethylene under pressure forms a solid hydrate with water and the phase-equilibria at high pressures had to be measured to find the minimum temperatures which would prevent blockages in pipe lines.

80-c.c. high-pressure reaction vessel for laboratory studies.

Secondary compression was very difficult. The only machine known to work at 2000 atmospheres and above had been obtained from Professor Michels of Amsterdam for general laboratory service. This used U-tubes with mercury seals. Gas on one side was compressed and displaced over mercury by forcing oil from hydraulic intensifiers in to the other side. There was an elaborate system of valves and electrical controls to make the working automatic. Many problems had to be solved to make



2000-atmosphere compressor of the first commercial plant, 1939.

this machine capable of working without interruption for days on end, and eventually to progress to larger machines at first of ten times the size and later fifty times as large. For example, an unexpected problem was the loss of mercury by emulsification in the oil. Methods of making up the losses by injecting mercury without stopping the machine had to be found, and means of separating mercury from the returned oil had to be worked out.

These machines were condemned in principle by all engineers who saw them. Apart from difficulties in manufacture, they required standards of cleanliness and constant attention beyond anything previously experienced in chemical plant machinery but they had to be persisted with in the absence of anything better. The engineers eventually overcame the problems of designing more conventional compressors for the high pressures, and the last of the original designs ceased work in 1950. But it is worth stressing that the development of polythene, and its subsequent large-scale war-time production in this country for radar uses depended on a highly unconventional piece of laboratory equipment, designed by a physicist for use by physical chemists.

To help in plant design, a variety of calculations on the physical properties of ethylene were made. The most noteworthy of these was the construction of a thermodynamic diagram for ethylene, to show the entropy, enthalpy and density of ethylene at pressures up to 1500 atmospheres and temperatures up to 250° C. This was of great value, because of the large departure of the gas from ideal behaviour at high pressures.

Larger vessels than those of the laboratory were of course required. Here knowledge gained in the laboratory study of high-pressure physics and chemistry during the early 1930s proved its value. The leading part in this work was of course that of the engineer, but close collaboration with the chemist was essential. The engineer prefers a high-pressure vessel to have as few and as small openings and as great a symmetry as possible because this allows him to design more precisely. The chemist for his purposes is apt to ask for many holes for thermocouples, for admitting reagents and removing product. Both have to give way to some extent. Vessel sizes were increased in as big steps as we dared to take, first from 1-litre to 10-litres, as used in the semi-technical plant. The first commercial plant of 1939 had 50-litre vessels and these led in 1941 to 250-litre vessels. These developments required great ingenuity on the part of the engineer designers, rigid control by the metallurgists, and painstaking standards in machining. New types of closures and valves were developed. It is doubtful whether the previously accepted methods of design would have provided serviceable vessels; certainly they would have had very much thicker walls, and would have been of extreme weight and clumsiness.

The Reaction

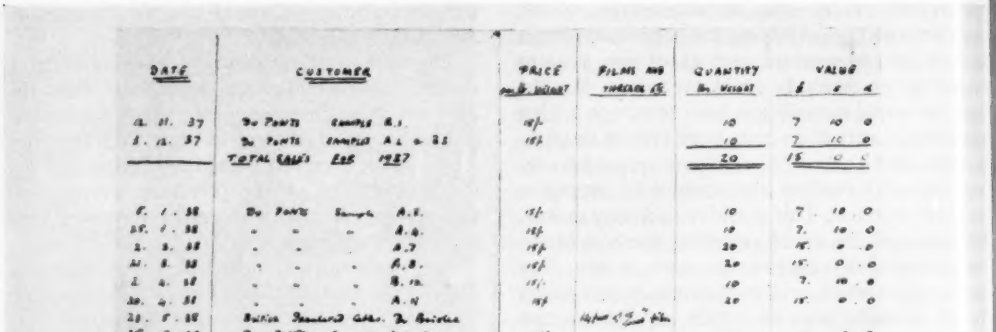
Early experiments had often ended in explosions, leaving only carbon, hydrogen and methane. The underlying cause was the very large heat of reaction

—over 800 cal./g.—and the acceleration of the reaction with rising temperature or pressure. Strict control of temperature and of oxygen content would be necessary to avoid explosions, but the process would nevertheless have to run at a high reaction velocity if its costs were ever to be comparable with those of low-pressure processes, for high-pressure reactors are much more expensive per litre than low. This would require very powerful and rapid means of absorbing the heat of the reaction and of changing its speed at will. The steady state which was wanted would necessarily be an unstable one, in which any uncorrected disturbance would continue to grow either towards an explosion or to a cessation of reaction. The requirements were stringent for explosions had developed in a second or two from a quiescent state and although the reaction velocity is doubled by only a few degrees rise of temperature, the heat of reaction is so great that a 25 per cent conversion without heat removal would raise the temperature 300° C.

The semi-technical plant was assembled from a 10-litre 3000-atmosphere autoclave and the 2500 atm. laboratory compressor which was capable of about 10 lb. of ethylene an hour. Both the autoclave and the compressor had been designed before the development of the polythene process was undertaken, so that the combination was not particularly appropriate to the purpose in mind.

The powerful and instantaneous influence of pressure on reaction velocity was used for control, by deliberately reducing pressure at the first signs of the temperature rising from the desired value in the region of 200° C. and increasing it at signs of a fall, by making adjustments to the valve at the bottom of the autoclave through which the product and unreacted gas passed out. Experience with this equipment, during which the instrumentation was greatly refined, (galvanometers were used for

Wallerscote polythene plant in 1940. The site of the semi-technical plant and the first commercial plant.



DATE	CUSTOMER	PRICE per lb. weight	FILMS AND THICKNESS	QUANTITY lbs. weight	VALUE £	s	d
12. 11. 37	Du Ponts Samples B.1.	15/-		10	7	10	0
3. 12. 37	Du Ponts Samples A.1 & B.1	15/-		10	7	10	0
	TOTAL SALES FOR 1937			20	15	0	0
6. 1. 38	Du Ponts Samples A.1.	15/-		10	7	10	0
27. 1. 38	" " " A.4.	15/-		10	7	10	0
2. 3. 38	" " " A.7	15/-		20	15	0	0
21. 3. 38	" " " A.8.	15/-		20	15	0	0
2. 4. 38	" " " B.12.	15/-		10	7	10	0
20. 4. 38	" " " A.N	15/-		20	15	0	0
28. 5. 38	British Standard Cable. Du Pont Co.		14 lbs of 3" film				
28. 5. 38	Du Ponts Samples A.13, B.12	15/-		20	15	0	0
15. 6. 38	Submarine Cable Co. J. Dunn.	15/-		5	3	15	0
30. 6. 38	C.A.P. (2 tons of [illegible] Films)	15/-		5	3	15	0
19. 8. 38	Standard Telephone Cables (for submarine telegraph)	15/-		5	3	15	0
26. 8. 38	Du Ponts Samples B 15" Quick Cy	15/-		10	7	10	0
13. 9. 38	British Insulated Cable Co. Brixton	No charge	100 yds film				
5. 1. 38	F.A. Hughes & Co. Cy	15/-		1		15	0
12. 10. 38	15 lbs A, 15 lbs Cy & Submarine Cables.	15/-		[illegible]	[illegible]	[illegible]	[illegible]
27. 10. 38	20 lbs Cy Du Pont.	15/-		20	15	0	0
10 [illegible] 38	A.R. Swedish Cable Ltd. Cy	15/-		[illegible]		7	6
[illegible] 38	20 lbs A for Du Ponts	15/-		20	15	0	0
7 [illegible] 38	1 lb A. British Standard Cable	15/-		1		15	0
16 [illegible] 38	Du Ponts. A7.	15/-		140	75	0	0
14 [illegible] 38	1 lb. [illegible] for A.R. Electric	15/-		1		15	0
	TOTAL SALES FOR 1938			390¼	292	13	6

Original record of the first polythene sales entered in a laboratory note book.

the indication of temperature), showed how the risk of explosions might be minimized, and the great heat of reaction brought under control, and demonstrated the feasibility of a truly continuous process, offering the economic advantages of a rapid, steady rate of production of a product whose properties could be controlled by control of reaction pressure and temperature, and of the few parts per million of oxygen added to the ethylene as catalyst. The first ton of polythene was made in this semi-technical plant by Christmas 1938.

When full-scale production had to be planned, conventional chemical engineering principles suggested that the only sure way to deal with much greater heat production when the largest scales of operation were reached would be to provide more and more wall surface for cooling, and that the simple way to do this would be to use a long tube in which the gas in its passage would first be heated to reaction temperature and then cooled to remove the heat of reaction.

Although the laboratory compressor was tried with a tube, it was not large enough to test such proposals satisfactorily because it could not provide a highly turbulent flow in a tube wide enough not to block. There were also indications that the tube gave a much lower pass conversion, at a time when as much polythene as possible was wanted from whatever gas was available. A decision had to be made immediately and the design for the commercial plant adhered to the autoclave system. As soon as this plant started in September 1939 the behaviour of 50-litre autoclaves was closely studied and it was concluded that the autoclave system had much to recommend it for future design. The heat balance showed that heat absorption need not depend solely on wall cooling. Cold ethylene entered the reactor, but a substantial proportion left it unreacted, hot, at reaction temperature and so removed some heat of reaction. In fact a satisfactory conversion was obtainable without any cooling of the autoclave. As a result of these physico-chemical studies it was appreciated that in designing for still greater outputs the autoclave

system could offer the great advantage of avoiding increased difficulties of heat transfer.[2] Given such a means of heat control, much greater steady state reaction velocities can be obtained from relatively small increases in pressure. Although larger production would need larger compressors, there need be no comparable increase in autoclave volume. This principle has been employed very successfully ever since.

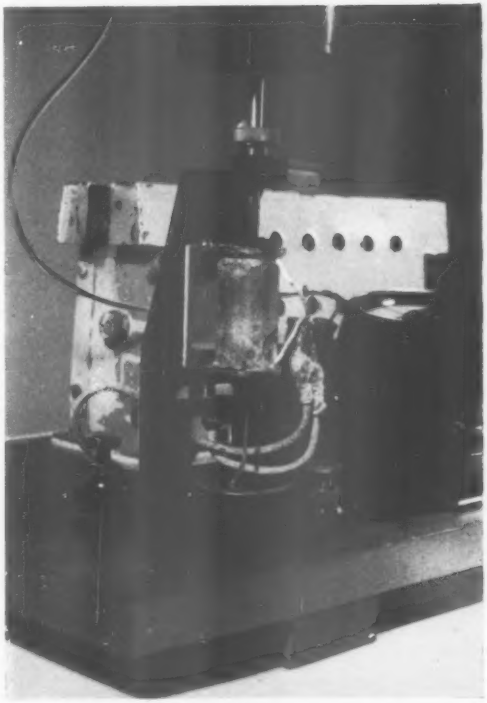
Much fuller consideration than I have mentioned was of course given to these and to many other problems of the control of the unstable reaction and the avoidance of explosion in the handling of high-pressure ethylene. Chemists and engineers both found that the key to an understanding of the problems was a good knowledge of physics.

Uses

Before the war experimental work on polythene fabrication had given samples of solvent-spun polythene yarn and of solvent-cast polythene film. When keen interest outside the chemical industry was shown in the possibility of using polythene

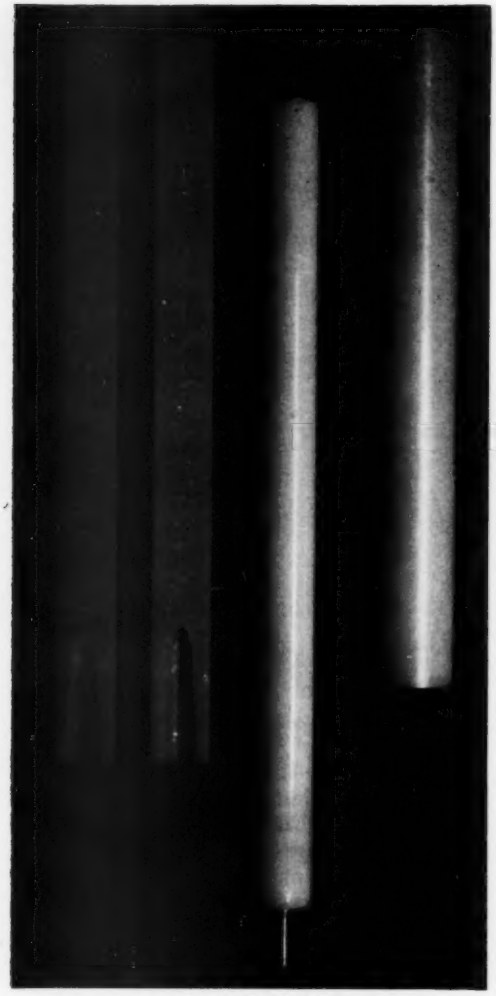
Polythene-insulated power cable used in the Wallerscote plant, 1942.

because of its excellent electrical properties, coupled with its flexibility and thermoplastic behaviour, instead of gutta percha in the manufacture of submarine cables, the chemists' attention became more and more focused on the problems of using polythene as a cable dielectric. With the approach of the war the immediate future of polythene became tied to radar and communication cables and equipment.



The first polythene grader in 1938.

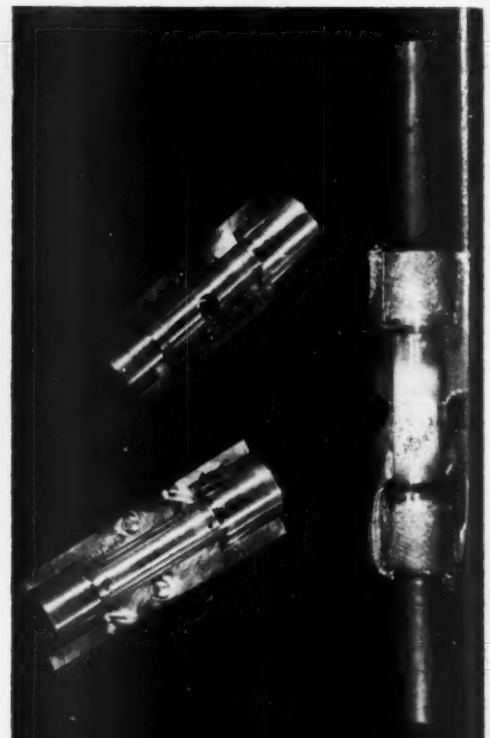
The main requirements in war uses were for extrudability in existing machinery, flexibility at minus 25° C. and below, and a very low power factor to give low dielectric losses in cables. In this work chemists and physicists collaborated closely with cable makers, making frequent visits to the works to see the difficulties at first-hand. Suitable test methods had to be set up. None of the existing standard methods of rubber testing gave a satisfactory test for extrudability, and new equipment had to be devised. This gave rise to the polythene grader—a simple viscometer in which the temperature and shear rates were chosen to have a reasonably close relation to the practical conditions in cable making. The test measures the 'grade number' of polythene; the higher the number, the greater the fluidity or the 'softer' the grade. This practical method of specifying the product came into general use. It was found that there was a limit of viscosity above which the process of extrusion



Extrusion-moulded rods, showing voids, 1941.

became too difficult for the machines available. Laboratory experiments and plant observations showed how product properties could be varied by choice of synthesis conditions. Viscosity could be reduced by reducing the average molecular weight of the product, by raising reaction temperature, but the brittleness temperature rose, towards room temperature, if molecular weight were too much reduced in the interests of greater fluidity. Thus the users' requirements were met by finding manufacturing conditions which gave the best compromise between low-temperature flexibility and ease of extrusion, which happened to be grade 20. Only towards the end of the war did much machinery capable of processing more viscous materials become available in this country. It was then possible to introduce polythene of greater average molecular weight with better low-temperature flexibility and solvent embrittlement resistance.

Even in the limited war-time field many problems came to the chemists. What caused voidages in extruded cable coverings? How was the ex-

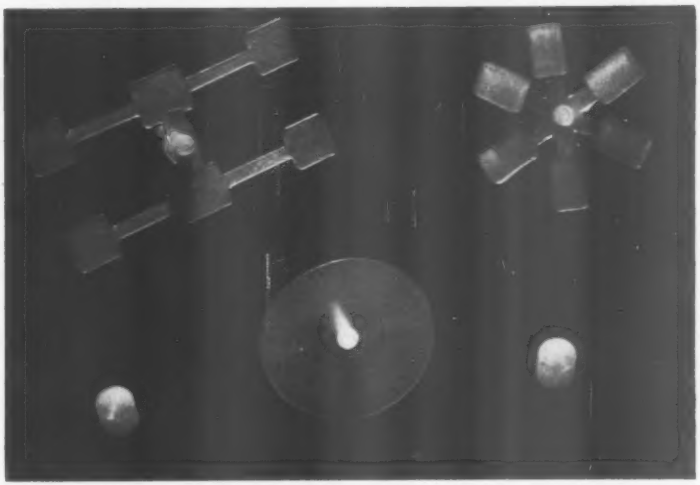


Experimental mould of 1939, for the jointing of polythene submarine cable at sea.

truded cable best cooled and how could large mouldings be made which would be undistorted and unstrained on cooling? To study such problems equipment for extrusion and moulding was installed in the laboratories, where it was employed, in co-operation with users, to overcome these difficulties.

But the problem which required most collaboration between the laboratory, the plant, and the users of polythene was its oxidation. It was soon noticed that the surface of molten polythene in air turns brown and hardens, but it was some time before it was appreciated that damage could be done by far less oxidation, with no visible change. Quite small uptakes of oxygen greatly increase the dielectric losses in polythene and at the same time gel forms which makes it impossible to get smooth, regular extrusions. An antioxidant was needed which would protect the product during fabrication without itself causing a deterioration of electrical properties. Because of the many points at which contamination could occur, the search was one in which the chemist had to be well aware of conditions in both the manufacturer's and the users' plants and he had to learn something of the connection between chemical constitution and electrical properties.

It is now fifteen years since the end of the period from which most of my examples are chosen. The same basic I.C.I. process is used in plants with a capacity of about 100,000 tons a year in this country and much more abroad, together supplying a large fraction of the world production, but there are now many different manufacturers of polythene concerned with the new questions which continually arise. Two different high-pressure processes came into use in America during the war, and a third in Germany at the end of the war. As a result of Professor Ziegler's remarkable discovery seven years ago, a low-pressure process is now established.



Injection-moulded test pieces, 1940.

The great increase in demand has come from post-war uses; packaging film and domestic moulded articles account for most tonnage, but there are developments in the use of polythene in cables, as the transatlantic telephone has shown. The very size of the industry and its continued high rate of growth give rise to a variety of specialised occupations for chemists, but it is still found that progress and improvement depend on a collaboration in which chemists, physicists and engineers are prepared to be interested in each other's science and technology.

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LOOKING AT science

FILMS ON TECHNICAL SUBJECTS

In our last issue we gave details of films on chemistry which have been shown at receptions for chemistry teachers, arranged by the British Association.

Below we list details of films on technical subjects, which have been included in the programmes arranged for teachers of technical subjects with the generous co-operation of Shell-Mex and B.P. Ltd., the National Coal Board (Durham Division), and the National Cash Register, Dundee.

It will be appreciated that these are but a few of the very large number of films available from many sources concerned with aspects of industrial science and technology. This particular list is published in the knowledge that the films have been found of interest and value to the teachers and lecturers to whom they have been shown, and are obtainable from libraries which include other films on aspects of technical education which will be helpful to those wishing to resort to visual aids in the presentation of their subject.

THE ADVANCING FLAME

Sound colour 20 minutes Gt. Britain 1960

Produced by Derek Stewart Productions for British Petroleum, and available on free loan from Shell-Mex and B.P. Ltd., Shell-Mex House, Strand, London, W.C.2.

An account of many new applications of heating in industry showing the value of oil either as a fuel or the use of the by-products of oil in the form of gas. Applications include distilling, food manufacture, brick manufacture, a laundry, steel production, domestic heating and electrical generation.

Suitable as background information for A-level students and technical college students.

BRITAIN'S WEALTH FROM COAL

Sound black and white 20 minutes Gt. Britain 1960

Produced by Basic Films, and available on free loan from the Film Library, National Coal Board, Hobart House, Grosvenor Place, S.W.1.

The geology of coal formation in Great Britain and an account of the board and pillar and longwall methods of coal mining, with some reference to problems of subsidence and the distribution of coal among the different types of consumers.

Suitable for geography teaching from O-level and of value in economics teaching.

A DAY AT THE RENAULT WORKS

Sound colour 25 minutes France 1959

Produced by Renault Film Service and available on hire from the G.B. Film Library, Aintree Road, Perivale, Greenford.

All the Renault factories in France together cover an area two-thirds that of Paris. This film shows something of the complex organisation and production techniques and is notable for some interesting sequences on the applications of automation to car manufacture.

Of particular interest for technical students and of value in advanced economics courses.

IN TWO DIMENSIONS

Sound colour 16 minutes Gt. Britain 1960

Produced by Kinocrat Productions for the National Cash Register Company and available on free loan from the National Cash Register Company.

Since ancient times knowledge has been recorded in permanent form and whilst modern business techniques require such aids as punch card analysis and tape recorders, there is still a need for

permanent information in readable form. This presents a particularly difficult problem for the small organisation which wishes to use new devices to supplement type and duplicated records.

This film shows the use of National Cash Register equipment in the small office, and gives some examples of the practical advantages of such equipment.

Useful for the commerce student to show the changes in office techniques.

THE INFORMATION MACHINE

Sound colour 11 minutes U.S.A. 1959

Produced by Charles and Ray Eames. Available on hire from the G.B. Film Library, Aintree Road, Perivale, Greenford, Middlesex.

A light-hearted cartoon account of the history of human thought and the contribution the computer can make to storing, analysing, and using the mass of data which confronts man today. The computer can simulate unrealised situations, such as rocket behaviour, aeroplane performance, the work of a complex chemical plant, or even the behaviour of whole communities.

Useful background material for the A-level student and for technical college students.

AN INTRODUCTION TO COMMINUTION

Sound colour 32 minutes Gt. Britain 1960

Produced by Film House Productions for International Combustion and available on free loan from G.B. Film Library, Aintree Road, Perivale, Greenford, Middlesex.

Comminution is the process of reducing particle size by breaking, grinding and crushing. This is a technique used in a very wide variety of industries ranging from cosmetics to gold and coal to chemicals.

This film surveys the early development of this ancient process and discusses some modern applications, showing the great variety of equipment devised to produce particles of many sizes.

Useful background material, particularly for technical students. Would be of direct value for pharmacy students.

AN INTRODUCTION TO MODERN GEARS

Sound black and white 31 minutes Gt. Britain 1958

Produced by Random Productions for Shell-Mex and B.P. Ltd., and available on free loan from Shell-Mex and B.P. Ltd., Shell-Mex House, Strand, London, W.C.2.

Planned as a training aid for schools, technical institutes and individual company training schemes this film is intended for students from their middle teens to early twenties. The style deliberately chosen is that of a filmed lecture which summarises the main functions of gears, classifies them into two groups—those with parallel or intersecting shafts and others; discusses the special characteristics of rolling friction associated with the first group, the principles of gear design, and the main techniques of gear cutting and generation.

Suitable for technical schools and colleges. Of indirect value as background material.

THE MAN ON THE ASSEMBLY LINE

Sound black and white 30 minutes Canada 1958

Produced by National Film Board of Canada and available on hire from the Central Film Library, Bromyard Avenue, London, W.3.

A study of the breakdown of an intelligent worker who has spent nine years on the assembly line in a motor car factory. This dramatised account is supplemented with observations by a commentator and comments by Prof. D. H. Wood, head of the Industrial Relations Centre, McGill University.

Useful for discussion for advanced students and as study material on sociology and psychology courses.

NEW POWER IN THEIR HANDS

Sound black and white 20 minutes Gt. Britain 1960

Produced by The National Coal Board Technical Film Unit and available on free loan from the Film Library, National Coal Board, Hobart House, Grosvenor Place, S.W.1.

The revolution in the coal industry is sometimes not appreciated by the general public, and this film is designed to present the miner and his industry to the people of Britain. With a free verse commentary spoken by Ewan McColl and *musique concrete* accompaniment, it shows the ingenious mechanisation of coal cutting which has spread over British

coal fields since the war, and the problems that have arisen from this. Mechanical coal cutters produce a large proportion of small coal and cannot distinguish between coal and stone. Cleaning and grading plants can sort coal from stone. Refinements in machinery can reduce the proportion of fine coal to lumps. This film is not only of interest to the technical teacher, but raises many problems concerned with the economics of production and distribution of one of our basic industries.

Designed for general release but of great interest to technical students and students of economics (with its detailed study of the impact of technical change on distribution and marketing problems).

SCHLIEREN

Sound colour 15 minutes Gt. Britain 1959

*Produced by Shell Film Unit for Shell International Petroleum, and available on free loan from Shell-Mex and B.P. Ltd., Shell-Mex House, Strand, London, W.C.*2.

The Shell Film Unit has introduced specialist and layman alike to brilliant examples of the use of schlieren photography in aerodynamic research. This film was made to explain the principles of that photographic technique. It includes examples of aerodynamic research but carries on to demonstrate its application in many homely fields of physics—a film which will not only interest the layman but may have a very useful role in the classroom. This film was awarded a Diploma of Merit by the British Association as the British film selected from those screened at the 1959 Harrogate Festival of Films in the service of Industry, which provided the best exposition of the scientific principles underlying an industrial process.

Useful background for O-level and A-level students.

THE SEA TOWER

Sound black and white 17 minutes Gt. Britain 1957

*Produced by Data Film Productions for the National Coal Board, and available on free loan from the Film Library, National Coal Board, Hobart House, Grosvenor Place, S.W.*1.

This is an account of a novel experiment by the Coal Board when they built a 180 ft. tower, mounted with a drilling rig, to prospect for coal in the Firth of Forth.

This is a technique which has long been used by oil companies, but it is the first experiment of its kind undertaken by the British coal industry.

Useful background information for technical, economics, and social studies students.

THIS IS AUTOMATION

Sound colour 30 minutes U.S.A. 1958

*Produced by Raphael Wolf Productions and available on free loan from the International General Electric Company of New York Ltd., 296/302 High Holborn, London, W.C.*1.

A film survey of some aspects of the development of automation in America since its first application in Oliver Evans' water mill in 1783. There are three main stages in the development of production technique—manual production, mechanisation, and automatic continuous production. This film argues that even the small firm should consider applying automation at some stage in its production processes.

Very useful for technical students but also of great value to those concerned with problems of economic and social change.

MATING SYSTEMS AND THE BREEDING OF PERENNIAL CROPS

By J. W. SIMMONDS *John Innes Institute, Hertford.*

About one-half of the food of mankind comes from seed-propagated annual plants. Of these, the inbreeders such as wheat, barley and peas, are bred to yield cultigens in the form of inbred lines. The outbreeders—maize is the most conspicuous example—must be handled differently; they are bred by means of variable mass populations or by inbreeding and hybridisation; inbreeding alone merely leads to loss of vigour. But in an outpollinated maize field there is a significant proportion of plants as vigorous as the best hybrids; these are the heterotic segregates and, if they could be vegetatively propagated, we should find that we should have isolated, in one step, clones as vigorous as the best hybrids. Even if it were possible, however, such propagation would certainly be impracticable on the commercial scale.

Now contrast the situation in perennial crops: they are mostly larger than annuals, populations are much smaller and, being longer lived, they are generally propagated at much longer intervals of time. Vegetative propagation of such plants then tends to become economically feasible (if it is physically possible). One cannot imagine planting an acre of wheat with very nearly one million cuttings for a single crop; but 200 banana suckers per acre for seven years of fruiting or 100 apple grafts on the same area for thirty years are perfectly practicable.

Our perennial crops are virtually all outbred, often very highly so, as Table 2 shows. The relation between habit and breeding system is striking. We may think of outbreeding as the 'normal' situation in most groups of plants. The inbreeding characteristic of the annual crops may sometimes (e.g. in wheat) reflect an origin from inbreeding ancestors; but, more often perhaps, it reflects (e.g. in the tomato) a change of mating system under domestication—as Harland (1955) has suggested for certain

TABLE 1

BREEDING SYSTEMS OF CROP PLANTS

	Inbred	*Outbred*
Annual	1. *Oryza** 2. *Triticum* 3. *Hordeum* 4. *Sorghum** 5. *Avena* 6. *Pisum* 7. *Phaseolus* 8. *Vicia** 9. *Arachis* 10. *Glycine* 11. *Trifolium* 12. *Lycopersicum* 13. *Gossypium** 14. *Nicotiana*	1. *Zea* 2. *Secale* 3. *Beta* 4. Cruciferae
	* Not infrequently outcrossed.	

	Inbred	*Outbred*
Perennial	1. *Prunus* (peach) (WVSA)	1. Gramineae (HSV) 2. *Trifolium* (HS) 3. *Medicago* (HS) 4. *Solanum* (HVA) 5. *Saccharum* (HVA) 6. *Prunus* (plums) (WVA) 7. *Malus* (WVA) 8. *Pyrus* (WVA) 9. *Rubus* (WVA) 10. *Mangifera* (WVSA) 11. *Citrus* (WVSA) 12. *Vitis* (WVA) 13. *Musa* (HVA) 14. *Ananas* (HVA) 15. *Fragaria* (HV) 16. *Theobroma* (WVS) 17. *Coffea* (WVS) 18. *Camellia* (WVSA) 19. *Cocos* (WS) 20. *Elaeis* (WS) 21. *Hevea* (WVS)

Key to symbols: H—herbaceous; W—woody; S—seed propagated; V—vegetatively propagated; A—aberrant sexual reproduction, sterilities, etc. (see Table 2)

West Indian maizes (see also Hutchinson, 1958). Whatever the history of the mating systems of our crops, the consequence for breeding perennials is clear: the immediate result of the outbreeding habit is that the plants, if inbred, lose vigour and

TABLE 2

EXAMPLES OF REPRODUCTIVE DERANGEMENTS IN PERENNIAL CROPS

Prunus (peach):	male sterility.
Solanum (potato):	sterility, correlated and deliberately bred.
Saccharum:	sterility, probably partly correlated, partly environmental; high polyploidy.
Musa:	sterility (causes very complex) correlated with human selection of parthenocarpy.
Prunus (plums, etc.):	some polyploidy.
Malus:	some triploidy.
Pyrus:	some triploidy.
Rubus:	hybridity maintained by apogamy.
Mangifera:	apogamy (polyembryony).
Citrus:	apogamy (polyembryony).
Vitis:	sterility, stenospermocarpy and parthenocarpy under human selection.
Camellia:	some female sterility.

the breeder must therefore use the methods of improvement appropriate to maize rather than those appropriate to wheat. To this point, qualified by the consequences of vegetative propagation, we shall return later.

Another feature of the breeding systems of these perennials is the frequent occurrence of abnormalities of sexual reproduction (Tables 1 and 2): thirteen out of the twenty-two crops named show various derangements and a fuller list would certainly show many more. Thus the four leading root crop-complexes of the tropics (the edible aroids, the yams, the sweet potato and the cassava) are all more or less seed-sterile. The causes of these derangements are often unknown but are certainly extremely various. Triploidy in apples and pears, high polyploidy in sugarcane, apogamy in mango and citrus, sterility as a correlated response to selection in potatoes and sugarcane, and sterility developed by deliberate human selection in bananas, potatoes and grapes; all these and probably other abnormalities occur. And the exceptional clonal crop such as the strawberry which is now reproductively normal (though it has changed its sexual habits under domestication) is normal for a good reason: the development of large and shapely fruits is absolutely dependent upon regular achene development and there has therefore been intense selection for reproductive stability.

Now consider what is meant by clonal propagation. A clone is a population of individuals of identical genotype descended from a single zygote. A pair of identical human twins is a clone; more strikingly, the litter of quadruplets regularly produced by the armadillo is also a clone; the 'King Edward' potato, the 'Gros Michel' banana, the 'Blenheim Orange' apple and the sugarcane B.H. 10/12 are all clones; and so are the apparently sexual seedlings produced apogamously by blackberries, oranges and mangoes. In agricultural practice clones are propagated by means of suckers, bulbs, cuttings, buddings, graftings and so forth. Clonal propagation varies very greatly in importance in the various perennial crops. It may be impossible, as in coconuts and oil-palms which, as long-term outbreeders, present the most tedious and intractable task the plant breeder can face. It may be possible but impracticable as with the pasture grasses and forages in which clonal propagation is a useful device for the plant breeder but (with a few local, mostly tropical, exceptions) too expensive to use commercially. It may be both possible and economically feasible but not always adopted as with cacao, rubber, mango and many other tropical fruits; the trend here is generally towards greater use of clones, conspicuously with cacao in the West Indies and rubber in Malaya. Finally, clonal propagation may be essential either because the plants are seedless (usually seed-sterile, as in bananas, pineapples and some sugarcanes and potatoes) or because they are so heterozygous that they produce only rare useful progeny (as with potatoes and most of the tree fruits).

What are the genetic consequences of the use of clones? Consider a field of outbred maize, a field of inbred wheat or cotton and a field of bananas. The first is conspicuously variable and there are as many genotypes as there are plants. The second is uniform to the eye and indeed uniform to more precise analysis for agronomic characters, but there will probably be some residual polymorphism in characters for which selection has not been

practised; there is thus little variability and there are few distinct genotypes but nevertheless all possibility of genetic change has not been lost. In the field of bananas, by contrast, there is one genotype only and no genetic variability. (We may neglect, for the present purpose, the effect of somatic mutation.) In short, inbreeding narrows the genetic base and clonal propagation narrows it still further. What a tremendous overall effect this has may be seen by considering a few examples: potatoes, bananas, sugarcane—none of these crops is represented in cultivation by more than a few hundred genotypes and even these are often interrelated. Thus the north temperate potatoes all spring primarily from a few dozen (admittedly heterozygous) genotypes, an almost incredibly narrow genetic base which is only now, very slowly, being broadened. One clone each forms 40 per cent and 80 per cent respectively of the crops of the U.S.A. and the United Kingdom.

What has happened with all these clonal crops is that sexual breeding followed by selection has identified and fixed heterotic well-adapted genotypes with consequent enormous gains in vigour, yield, adaptation, quality and, often, resistance to specific pathogens. But all this has been gained at the expense of genetic variability.

We must now consider the effects of the loss of variability and Table 3 shows this dramatically. The data of Stevens show that losses caused by disease are related to breeding system, outbred plants suffering less than inbred ones which are, in turn, less affected than clonal crops. Evidently, the genetic flexibility procured by outbreeding offers a protection against disease hazards that even an advanced technology cannot match. Put in another way, we may say that the loss of variability imposed by inbreeding or clonal propagation exposes one or a few unadaptable genotypes to new hazards which they cannot meet because they have lost the genetic means to do so. Broadly, pathogens, having short life cycles and enormous numbers of propagules in relation to the host's reproductive system, are much more adaptable than their hosts —with the results seen in the Table. To this we may add that clonal propagation not only permits the concurrent propagation of viruses but positively encourages it by reason of the removal of what we may regard as the 'sieve' of sexual reproduction. It is no accident that the record for the number of viruses in a crop plant is held by the potato with the remarkable number of sixteen (Stevens, 1948).

TABLE 3

ESTIMATES OF LOSSES CAUSED BY DISEASE IN THE U.S.A. (STEVENS, 1948)

Breeding system	*Numbers of crops*	*Value* $ m.	*Important diseases*	*Index of loss*	*Relative losses*
Clonal	7*	496	14	21·8	45
Selfed seed	7†	2278	17	29·4	13
Outbred seed	3‡	1568	5	9·6	6

* Potato, apple, sweet potato, peach, strawberry, pear, cherry.
† Wheat, oat, tobacco, bean, tomato, pea, cotton.
‡ Corn, beet, sweet corn.

Even an outbred crop, however, may lose variability under some breeding plans—as is surely happening now in North American maize. This crop has not yet suffered a really calamitous disease epidemic but it would not be surprising if one developed during the next few decades. The recent epidemic of maize rust in Africa offers a very pointed warning in this connexion; it occurred in maizes so narrowly based genetically that the resistance genes common in tropical American populations were unrepresented. Thus there is a sense in which we can say that man *creates* epidemics on his crops by inbreeding and, above all, by clonal propagation.

To summarise, the following are the characteristics of clonally propagated crops: they are outbreeders that display fixed heterosis; they are closely adapted but invariable and of very low long-term adaptability; and they are bred by means that often seem complex but are really basically simple—namely, the creation, recognition and fixation of vigorous heterozygotes. The intricacy and elegance of many of the methods used and the (often discouraging) difficulties of overcoming the sterilities and other derangements of the mating system do not alter the fact of basic simplicity.

Finally, I want to trail my coat. We have seen that the reduction of variability caused by inbreeding and its equivalent, clonal propagation, leads to inadaptability. The demands of modern machinery and markets are such that a premium is placed on uniformity so that the trend is towards the increasing use of few clones over ever larger

areas. The problem is to retain the great advantages of inbreeding and clonal systems but minimize the disadvantages.

There are three ways in which this can be tackled: we can broaden the genetic bases of breeding lines—as is done in potatoes and bananas by using wild plants as parents; we can hasten the flow of new varieties so that there is a relatively rapid turnover in time—as is successfully done with sugarcane; and we can use physical mixtures of varieties or clones—as Borlaug proposes to combat rust of wheat and as the Uganda peasant does in his banana garden. These methods are potentially powerful (even if generally neglected) and they can do something to mitigate the disadvantages of genetic invariability. In this respect, the peasant (who generally eschews monocrop culture and maintains mixtures of genotypes in his fields) operates on an inherently sounder basis than the 'scientific' agriculturist who discards variability at the expense of future adaptation. 'In the conservation of variability lies the hope of progress' (Hutchinson, 1958).

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ON THE ECOLOGY OF HIGHER FUNGI

By Prof. Dr. GÖSTA LINDEBERG *Department of Microbiology, Agricultural College of Norway*

Observations on the occurrence of toadstools in their natural habitats demonstrate that they belong to different ecological groups.

Numerous species grow directly on the surface litter of dead plant residues, their mycelia penetrating the litter and causing it to become bleached, brittle, and finally entirely broken down. This group includes many species with small sporophores (*Collybia, Mycena, Marasmius, Clavaria*) and some species with large sporophores (*Lepiota, Clitocybe, Tricholoma, Psalliota*).

Other species are associated with certain trees but do not attack litter (*Boletus, Amanita, Cortinarius, Lactarius, Russula, Cantharellus*, and certain species of *Tricholoma*). Mycelia from such species disappear into the soil at short distances from the base of the sporophore stalk. The association with certain trees is a very remarkable feature. It is a well-established fact that these fungi are symbionts of their respective trees, forming their typical mycorrhizae.

A third group of species (e.g. of the Polyporales) grow on dead or living trees.

Of course, to these ecological groups could be added the coprophilous types, fungi occurring on burnt ground, and fungi parasitising the sporophores of other and larger species, but we shall here concern ourselves with the soil-inhabiting types and consider how far their occurrence can be explained on our present knowledge of their physiology. This particular field has been studied, for many years, by Professor Melin and his school at the Institute of Physiological Botany, University of Uppsala. Having been associated with this work, I should like to deal with certain aspects of it in this discourse.

Careful observations in nature may identify a fungus as a litter-decomposing species, but in many instances proof of this can only be obtained by experimentation. Falck thoroughly investigated the chemical changes in wood caused by various wood-rotting fungi, and demonstrated the existence of two types: the white-rot fungi, and the brown-rot fungi. He proved that the former simultaneously attack lignin and cellulose, while the latter attack only the cellulose and are unable to decompose lignin. He assumed that the litter-decomposing fungi behave in a similar manner. Cultivating *Clitocybe nebularis* on sterilised beech leaves, he proved that it decomposed both lignin and cellulose, i.e. it behaved as a white-rot. *Coniophora cerebella*, cultivated on sterilised pine needles, decomposed only cellulose and behaved as a brown-rot.[2]

Falck supposed both types to be common in forest soils and thought that the course of humus formation in such soils was governed by the preponderance of one type or the other. Unfortunately, the *Coniophora* studied by Falck does not belong to the soil-inhabiting fungi but to the flora of colonised tree stumps.

To shed more light on the ability of soil-inhabiting hymenomycetes to decompose lignin and cellulose, Lindeberg [7, 8] cultivated forty-six species on sterilised litters and determined the amounts of dry matter, cellulose, and lignin decomposed. Some results are given in Table 1.

Clavaria gracilis was the only species found that attacked lignin without decomposing cellulose. All other species decomposed both cellulose and lignin. No species corresponded to Falck's *Coniophora*-type.

In the nineteenth century, Hartig and Frank studied the transformed short roots of forest trees known as mycorrhizae. These are dichotomously branched in pine and monopodially branched in spruce. The outer surface of each mycorrhiza is a fungal mantle, and in young specimens, numerous hyphae pass from the mantle into the soil. From the inner side of the mantle hyphae penetrate the middle lamellae of the root cortex, forming a fine network of filaments referred to as the 'Hartig net'. Mycorrhizae are devoid of root hairs.

Such ectotrophic mycorrhizae have been intensively studied by Melin and his associates.

Melin[10, 11, 12] proved experimentally that certain hymenomycetes, normally associated with forest trees, actually constitute the fungal partner of their mycorrhizae. Seedlings, grown aseptically, were inoculated with pure cultures of various hymenomycetes and the formation of mycorrhizae was taken as a proof that the species tested belonged to the mycorrhizal fungi of that tree. Later experiments, by other workers, confirmed and extended Melin's observations, so that today we know that several hymenomycetes (*Amanita*, *Boletus*, *Cantharellus*, *Clitopilus*, *Cortinarius*, *Entoloma*, *Lactarius*, *Russula*, *Tricholoma*) and some gasteromycetes (*Rhizopogon*, *Scleroderma*) act as the fungal partners of tree mycorrhizae.

TABLE 1

LOSS OF DRY WEIGHT AND DECOMPOSITION OF LIGNIN AND CELLULOSE IN BEECH LITTER CAUSED BY VARIOUS BASIDIOMYCETES[7, 8]

	Decomposition (%)		
Species	*Dry matter*	*Lignin*	*Cellulose*
Clavaria dendroidea	25	51	33
Clavaria gracilis	13	39	1
Collybia butyracea	29	77	16
Collybia dryophila	37	76	70
Lepiota procera	22	55	28
Mycena epipterygia	39	57	74
Mycena inclinata	47	69	83
Marasmius alliaceus	51	72	85
Marasmius putillus	34	68	20
Marasmius scorodonius	36	57	67

The mycorrhizal fungi of the forest trees vary in their degree of specialisation. *Boletus elegans* is confined to larch, *Lactarius deliciosus* forms mycorrhizae with pine and spruce, and *Amanita muscaria* with pine, spruce, larch and birch. Hence, fungal species, not closely related taxonomically, can form mycorrhizae with the same tree species.

In comparing the nutritional requirements of litter-decomposing and mycorrhiza-forming hymenomycetes, an attempt will be made to evaluate possible differences in relation to their respective ecological characteristics.

In general, hymenomycetes are thiamine-dependent, i.e. this vitamin is required for the growth of such fungi on synthetic media. In many species, the addition of other vitamins increases the growth rate. Heterotrophy for vitamins can be total or partial. Table 2 shows the requirements of certain species in the two groups reviewed. The results indicate that no characteristic differences exist between species of the two groups in respect of their vitamin requirements.

TABLE 2

GROWTH FACTOR REQUIREMENTS OF SOME LITTER-DECOMPOSING AND MYCORRHIZA-FORMING BASIDIOMYCETES[7, 14, 18]

Species	*Thiamine*	*Biotin*	*PAB*	*Pantothenic acid*	*Nicotinic acid*
Litter-decomposing					
Marasmius androsaceus	+	+			
Marasmius perforans	+	(+)			
Marasmius scorodonius	+	–			
Tricholoma brevipes	+	–	(+)	–	–
Tricholoma fumosum	+	–	–	–	(–)
Tricholoma gambosum	+	–	–	(+)	–
Mycorrhiza-forming					
Lactarius delicious	+	–	–	–	(–)
Tricholoma imbricatum	+	–	–	(+)	–

Absolutely dependent: +
Partially dependent: (+)
Not dependent: –
Not tested: blanks

With many other fungi, addition of hydrolysed casein to growth media for hymenomycetes in many cases increases the growth rate which suggests that the ability of certain species to synthesise amino acids is reduced. So far, only limited investigations on the amino acid requirements of these fungi have been carried out. Norkrans [18] investigated various species of *Tricholoma* (Table 3). A reduced ability to synthesise amino acids was observed within both groups, and no general difference in pattern was evident for this character.

With regard to inorganic sources of nitrogen, ammonium ions are easily assimilated by litter-decomposing as well as by mycorrhiza-forming species, but only a few are able to assimilate nitrate ions.

Soluble carbohydrates are easily used by most hymenomycetes. However, among the two groups discussed here, only the litter-decomposers can use cellulose as a sole carbon source. In all probability, this distinction between the two groups is ecologically important.

Studies by many authors have shown that basidiomycetes generally grow more slowly than phycomycetes and most ascomycetes, which means that they are handicapped in competition for easily available energy sources. Phycomycetes are able to outstrip competitors in colonising such ephemeral carbon compounds as sugars, which are the first to disappear on the exploitation of dead plant tissues by fungi.[5] Hence, the availability of other carbon sources will be a deciding ecological factor for basidiomycetes.

TABLE 3

REQUIREMENTS FOR AMINO ACIDS OF VARIOUS *Tricholoma* SPECIES[18]

Species	Glutamic	Aspartic	Proline	Hydroxyproline	Histidine	Tryptophane
Litter-decomposing						
T. brevipes	(+)	(+)	–	–	–	–
T. fumosum*	–	–	–	–	–	(+)
T. gambosum	(+)	–	–	(+)	(+)	–
T. nudum	(+)	–	–	–	–	(+)
Mycorrhiza-forming						
T. flavobrunneum	–	–	–	–	–	–
T. imbricatum	(+)	(+)	(+)			
T. pessundatum	(+)	–	–	–	–	–
T. vaccinum	(+)	(+)	–	–	–	–

* Also mycorrhiza-forming.
Degree of requirement indicated as in Table 2.

The ability of litter-decomposing species to attack cellulose and lignin will provide them with abundant carbon and energy supplies. Saito[21] carried out experiments in which hymenomycetes were grown on sterilised beech litter, along with certain phycomycetes and ascomycetes. In such mixed cultures, growth of hymenomycetes followed the initial 'flare-up' of phycomycetes and ascomycetes. After a long period, during which hymenomycetes were dominant a secondary phase of phycomycetes and ascomycetes occurred, possibly as a result of the release of suitable nutrients by the activity of the hymenomycetes.

Frank, in 1885, expressed the view that mycorrhiza-forming fungi depend on trees for their carbohydrate supply, and, in that respect may be regarded as parasites. Observations by Romell[20] support this view. Trenches were dug between trees in a spruce forest, and iron sheets were placed against the trench sides before the soil excavated was replaced. All roots crossing the trenches were cut off, and no tree growth was allowed within the trenched areas. In the autumn, sporophores of mycorrhiza-forming species occurred only outside the trenched areas where close connection with living roots could be developed. On the other hand, typical litter-decomposers occurred also within the trenched areas.

Björkman[1] demonstrated experimentally the truth of Frank's theory. Studying the influence of nutritional factors on mycorrhiza-formation in pine, he found that it was primarily affected by factors determining the sugar content of the rootlets. Increasing light intensity favoured the formation, and a severe lack of nitrogen and phosphorus reduced growth as well as mycorrhiza-formation. A moderate scarcity of these elements favoured mycorrhiza-formation. Determinations of reducing sugar contents of roots showed that high levels of sugar stimulated mycorrhiza-formation (Table 4).

TABLE 4

MYCORRHIZA-FORMATION IN PINE AT DIFFERENT LIGHT INTENSITIES AND CONCENTRATIONS OF NITROGEN AND PHOSPHORUS[1]

Conditions	Contents of of reducing sugars in the roots	Frequency of mycorrhizae
Light suboptimal, varying conc. of N or P	low	low
Light optimal,		
N- and P-conc. high	low	low
N-conc. high, P-conc. low	high	high
N-conc. low, P-conc. high	high	high

Melin and Nilsson,[17] using tracer techniques, showed that organic compounds produced in pine needles by photosynthesis were rapidly transported to root tips as well as to the mantles of the mycorrhizal fungi.

If we ask ourselves about the importance of the mycorrhizal fungi to the trees, it is necessary to turn again to the remarkable paper by Frank in 1885, in which he stressed the beneficial effects of mycorrhizal formation to trees. He suggested that hyphae, passing from the mantle into the soil, function as nutrient-absorbing equivalents of the root-hairs.

Stahl, in 1900, further developed the view that tree mycorrhizae function as nutrient-absorbing structures, and that in some soils they are more effective than uninfected roots. Studying the growth of pine and spruce seedlings on trenched peat-bogs in northern Sweden, Melin[9] found a

close connection between the development of seedlings and the formation of mycorrhizae in their root systems. Later works by several investigators have supported the view that the mycorrhizae of trees are nutrient-absorbing structures, and that the fungal partners are beneficial to, or even necessary for the trees.

A definite proof that these fungi do transport nutrient salts from soil to roots of trees was obtained only after the introduction of tracer techniques. Combining such techniques with the aseptic method of raising and inoculating seedlings, Melin and Nilsson[17] exposed only the hyphae of the mycorrhizal fungi to labelled phosphate, and later determined the radioactivity in various parts of the pine seedlings. As early as 7½ hours after exposure of mycelium to labelled phosphate, the isotope could be detected in the pine needles. Further experiments showed that hyphae of *Boletus variegatus* in mycorrhizal connection with pine were able to transfer nitrogen from N^{15} labelled nitrogen sources to the seedlings. Other experiments proved that metal cations were transferred to the tree roots by mycelia.

The physiology of salt absorption by ectotrophic mycorrhizae has recently been extensively treated by Harley.[6]

Although mycorrhizal fungi no doubt utilise products of photosynthesis of trees as carbon and energy sources, Melin[15] has shown that these fungi also obtain essential metabolites from tree roots. Excised pine roots were grown aseptically in suitable nutrient solutions, and were then brought into contact with suspensions of various mycorrhizal fungi. With rapidly growing species, an intense development of hyphae round the roots could be observed after a few days, whereas control flasks showed scarcely visible hyphal development. The growth-stimulating effect of the roots was still more pronounced for species which earlier had been found to grow very poorly in synthetic media (e.g. *Russula xerampelina*). Some results are given in Table 5. The active principle probably consists of a metabolite (or metabolites) which the fungi cannot synthesise or can only synthesise in suboptimal quantities. It has been termed the M. factor.

Ecologically, spore germination of mycorrhizal and of litter-decomposing fungi is of considerable interest. In general, the latter fungi germinate rapidly in simple media, while germination of the former is difficult to induce. However, Fries[4] found that spores of species of *Tricholoma*, *Amanita*, *Paxillus*, *Boletus*, *Hydnum* and *Craterellus* germinated in ordinary media in the presence

TABLE 5

GROWTH-PROMOTING EFFECT OF EXCISED PINE ROOTS ON VARIOUS MYCORRHIZAL BASIDIOMYCETES. BASAL MEDIUM SUPPLEMENTED WITH B-VITAMINS AND AMINO ACIDS[15]

Species	*Incubation time in days*	*Dry weight Relative value*	
		Without root	*With root*
Boletus edulis	14	26	100
Boletus subtementosus	11	66	100
Boletus variegatus	10	20	100
Amanita muscaria	22	44	100
Cortinarius glaucopus	21	7	100
Pholiota caperata	22	6	100
Russula xerampelina	38	1	100

of growing yeasts. Sometimes growing mycelia of other fungi had a similar but weaker effect. Interesting results were obtained by Melin[16] with respect to the influence of growing pine roots on the germination of spores of mycorrhizal fungi: thus, spores of Russula species, which had earlier given negative results, germinated under the influence of growing roots. He suggested that the active principle was the M. factor, or part of this factor. This would mean that spores of mycorrhizal fungi are heterotrophic for one or more metabolites, formed and exuded by tree roots. In this connection, the experiments of Robertson,[19] indicating that mycorrhizal inoculum may be airborne, are of great interest.

Direct observations in the field indicate that mycorrhizal fungi do not grow on litter. With this in mind, Melin [13] studied the effect of aqueous litter extracts on the growth of mycorrhizal and litter-decomposing species in synthetic media. In low concentrations, the extracts had a strong growth-promoting effect on such fungi. The effect was shown to depend on both organic and inorganic components of the extract.

However, when high concentrations of litter extracts were used, the two types of fungi responded in different ways. In mycorrhizal fungi growth was inhibited; in litter fungi such concentrations induced stimulation (Fig. 1). The sensitivity of mycorrhizal fungi to higher concentrations of litter

extracts might possibly be due to the presence in these extracts of phenolic compounds or their oxidation products (cf. Harley[6]). Probably, such substances are of great ecological importance.

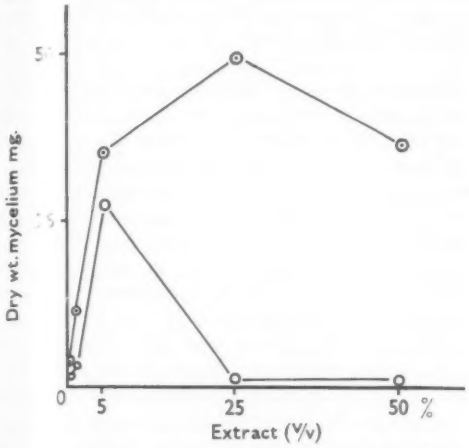

Fig. 1.—Effect of extracts of *Populus tremula* leaf-litter on growth of *Lactarius deliciosus* (o) and *Clavaria dendroidea* (○)

Thus, the main features of the nutritional requirements of the soil-inhabiting hymenomycetes, and, especially, the relations between the mycorrhizal fungi and their hosts, have been elucidated. Ecologically, the ability of the litter-decomposing fungi to attack lignin and cellulose, and the power of the mycorrhizal fungi to use the carbohydrates of the tree-roots, seem to be of great importance. However, the specialisation characterising the occurrence of the species within both groups cannot be explained on the basis of our present knowledge of their physiology. Organic substances, exuded by the roots, or leached out from the dead plant residues, most probably influence the growth of these fungi and partly determine their ability to compete with other organisms in the various loci in nature. Current research to a great extent aims at elucidating these problems.

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BASIC PATTERNS OF SETTLEMENT DISTRIBUTION IN NORTHERN ENGLAND

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The purpose of this paper is to reconsider, in the light of recent findings on settlement in Wales, the early history of settlement in northern England. This area, here defined as embracing the six northern counties, has been chosen since it corresponds broadly to the non-Scottish portions of the old kingdom of Northumbria. Within this kingdom the most challenging problems of early settlement arise in the south-eastern sector, and for this reason Yorkshire has been singled out for special consideration.

It has long been customary for students of the history of settlement to regard nucleated rural settlements, whether in Northumbria or in the whole of England, as an essentially Germanic contribution to the making of the landscape. According to the traditional view, villages were established during the disturbed centuries following the decline of Roman power in Britain when groups of free and equal Anglo-Saxons settled as pioneers on lands hitherto virgin or vacated by the Romano-Britons; for the adherents of this thesis envisaged an almost complete extermination of this pre-existing population, especially in eastern districts. Smaller nucleated hamlets are regarded as an expression of a still later phase of settlement, occasioned either by an outward expansion of population from the villages or by Scandinavian pioneering during the ninth century A.D. in areas large or small hitherto neglected.

That there had been an antecedent occupation of northern England by Celtic communities is indicated by surviving material remains from the Celtic Iron Age and by Brittonic place-names. Moreover, Bede described how Ethelfrid of Northumbria in A.D. 603 'overran a greater area than any other kings or chiefs, exterminating or enslaving the (British) inhabitants, extorting tribute, and annexing their lands for the English'. On the basis of such evidence, some vague observations about a heritage of Celtic settlement have been advanced for parts of northern England and especially the areas north of the Tees, but for south-eastern Yorkshire, the core of the early kingdom of Deira, no such claim has ever been advanced. Thus, on the basis of the evidence provided by open-field systems, central and eastern Yorkshire has always been classified with the Midlands as an area where characteristic Germanic settlement forms are well represented. Nevertheless recent findings on early settlement in Wales suggest that, until the possibility of a significant Celtic contribution is at least put to the test, no convincing explanation of settlement history is likely to be advanced, whether for northern England or for those other large areas of Europe where Germanic settlement was effected in districts once occupied by Celts.

All previous investigators have claimed that as late as the Middle Ages, the Celts had a social organisation based almost exclusively on kinship and an economic organisation based overwhelmingly on semi-nomadic pastoralism. With its physically fragmented countryside, moist climate and modern predominance of animal husbandry, western Britain was readily envisaged as a late surviving Wild West, inhabited by Celtic cowboys. Thus the scattered farmsteads of the present-day Celtic West, so appropriate for animal husbandry, came to be accepted as the norm of Celtic settlement through the ages; and somehow or other the small nucleated hamlets of western Britain also came to be regarded as an expression of pastoral arrangements.

Not unnaturally therefore Jackson, in a recent analysis, claimed that 'British villages were small and scattered, of the "non-nucleated" type, which would not suit the English with their nucleated villages' and that the English 'may hardly have recognised the dispersed British homesteads as constituting villages at all and hence never learned their names'.[1] The presence of Germanic place-names and the relative absence of Brittonic place-names in England was the basis of the traditional

interpretation of settlement in Britain. Thus Jackson's observations do at least open up the possibility that the Celts contributed to the making of the English landscape notwithstanding the failure of many Brittonic place-names to survive. Moreover he adduced sufficient linguistic evidence to undermine, even for eastern Britain, the old theory of the complete extermination of the Celts and argued for a bi-lingual phase when English settlement was being effected. Yet to Jackson, no less than to earlier scholars like Ekwall, the survival of settlements inhabited by Celts was the exception rather than the rule. Recent studies of early settlement in Wales, however, suggest that, insofar as his views were based on the alleged characteristics of Celtic settlement, Jackson underestimated the possibilities of a Celtic survival.

The traditional view of Celtic social organisation was derived in the main from the early medieval law codes of Ireland and Wales and from early epic literature. These sources reveal a warrior society whose wealth was counted in cattle and whose heroic exploits centred on cattle raiding. For Wales, administrative records of the Middle Ages make it clear that these conditions applied to but a small ruling class. Bondmen, whose economy had a stronger arable bias than that of their overlords, constituted an unfree majority in Welsh society. These bondmen resided in small hamlets, each containing about nine houses, but small though they were these hamlets were nucleated settlements. In Wales such hamlets were the most characteristic units of early settlement for which we have written evidence; there were also some scattered farms but these became typical features of the Welsh countryside only in the later Middle Ages.

Each hamlet community cultivated a permanent open-field shareland and grazed common pastures, parts of which were periodically subject to temporary outfield cultivation. The hamlet was the local unit of agrarian co-operation but at the same time it was part of a wider grouping of settlements, subject to the authority of a lord. The bondmen in Welsh society held their land in return for rents and services to this lord. These obligations included grain and cattle rents, the entertainment of the lord and his retainers at certain seasonal circuits, the construction of the lord's court (*aula* or *llys*) and the cultivation of the lord's demesne lands. These demesnes were normally situated on the best soil within the administrative area or neighbourhood subject to the lord's control; since they were cultivated for the maintenance of the court, this too was situated nearby, on the outskirts of a bond hamlet known as a mayor's settlement (*maerdref*), and so-named for it was the abode of the land mayor who directed the labour services of the neighbourhood bondmen.

For North Wales it has been demonstrated that some bond hamlets were in being long before the earliest English colonization was effected along the border. A few of the Welsh mayor's settlements, or adjacent lord's courts, bore the names of adjoining hill-forts and the majority were sited in the lowlands beneath hill-forts. At Dinorben, the original hall of the lord appears to have been sited within the ramparts of the Iron Age hill-fort and there is evidence to show that the construction of these fortifications, no less than that of the hall and the maintenance of its aristocratic occupants, was made possible by the rents and services contributed by the unfree inhabitants of a group of appendant bond hamlets. Some of these hamlets, to judge from the evidence of an asymmetrical winged ploughshare found in a late Roman context within the hill-fort, were already by early centuries A.D. established on the same fertile lowland sites they occupied in the Middle Ages.[2]

The direct archaeological evidence for early settlement, in the form of homestead sites or field systems, tends to survive best on lands regarded as marginal by later settlers and which may well have been marginal even in the eyes of the original settlers. For this reason, and also the operation of accident in archaeological discovery, this kind of evidence for northern England is best viewed against the background provided by the available evidence of place-names and administrative records.

The material for a satisfactory distribution map of Brittonic place-names in northern England does not yet exist but there are some types of English place-names which may be taken as evidence for the existence of small communities of Britons, living apart from the English settlers at least at the time of the English settlement. Such are the place-names in *walas* and *cumbran*, whereas place-names in *brettas* probably refer to such communities of Britons in being at the time of the Scandinavian settlement.[3] Thus the name Walton, applied to a settlement near Cartmell in the Lake District, is

made up of the Old English *wealh* meaning 'a foreigner, a Welshman or a serf' and the Old English *tun* meaning 'homestead or village' and so refers to a settlement inhabited by Welshmen or serfs. By no means all places named Walton have this meaning, for some have as their prefixes the Old English for 'forest' and others the Old English for 'wall', but in northern England there are no less than fourteen place-names which incorporate the Old English *wealh* and seven of these are Waltons. Similarly, within the same area, there are four place-names incorporating the element *cumbran* and nine incorporating *brettas*.

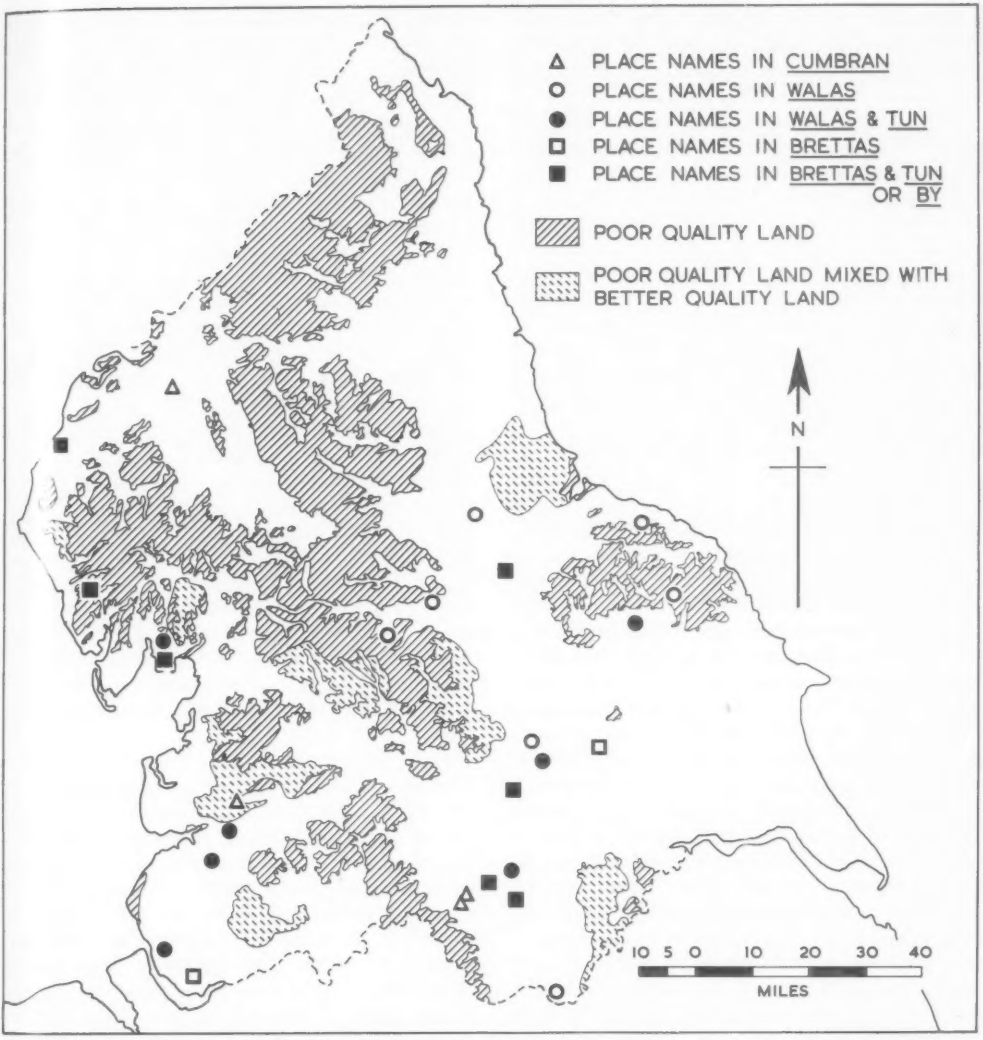
For reasons perhaps bound up with their presuppositions about Celtic society, most philologists have stressed that place-names indicative of a surviving British population in England occur on the poorest land and in remote areas. As a generalisation about Brittonic place-names this is true but it certainly does not apply to all of them and the exceptions may well be more important than the general rule. This generalisation is demonstrably untrue of the English place-names with which we are concerned. Ekwall used Walton and Birkby (the *by* or village of the Britons), near Cartmell, to support his claim that the Britons had to give up the best land and settle in the more remote parts on fairly high land.[4] In fact, however, both Walton and Birkby stood within a mile of Cartmell and at altitudes of less than 250 ft. In the same way, not one of the seven Waltons in northern England is sited on land of poor quality,[5] and only one of the other *wealh* names refers to a settlement so located (Fig. 1). The four names in *cumbran* all refer to places on soils of medium or good quality, as do all but one of the eleven names in *brettas*. Moreover the majority of these names refer to places in the lowlands.

Some philologists remain hesitant about the meaning 'Welsh' attached to *wealh* and have suggested that this element could equally well mean 'serf'. But, since the majority of Welshmen in the Dark Ages were unfree, the probability is that most of the Welsh survivors in England were in any case the servile tenants of English overlords. In the case of Cartmell, literary evidence supports this view for, according to the *History of Saint Cuthbert*, Ecgfrith, king of Northumbria, gave Cartmell 'et omnes Britannos cum eo' to the Church in the late seventh century. Even Ekwall conceded that there was no definite reason to doubt the substantial correctness of this phrase which tells us that in the Cartmell district a British population lived on, in a subject position after the Anglian invasion.

East of the Pennines likewise, the survival of a British population is confirmed by literary evidence. The Celtic principality of Elmet survived as an independent entity in the vicinity of Leeds until conquered by the Northumbrians in the early seventh century. Moreover Seebohm claimed that the *Wallerwente*, recorded in a fragment of law dated to the ninth century, referred to Welshmen residing in the Vale of York within six miles of the city of that name.

Further confirmation is provided by the administrative records of Northumbria in the Middle Ages. As Jolliffe demonstrated, there were in this area groups of townships administered from and appendant to a headquarters settlement containing a lord's court (*aula* or *mansio*).[6] To such a complex, in essence a discrete estate or federal manor, the name *shire* was applied. The inhabitants of each appendant township were responsible for grain and cattle payments to the lord of the shire. Likewise they were responsible for the entertainment of the lord and his retinue at certain seasonal progresses. Various constructional duties and repairs of the *mansio* were apportioned equally among the townships of the shire. In addition the tenants of these townships performed light labour services of ploughing, harrowing and harvesting on the limited areas of demesne which adjoined the *mansio*. Altogether, there was a great organisation of service by which a countryside supported the central *caput*. Peasant farming in the townships was fairly well developed in the twelfth century but, according to Jolliffe, arable farming on the demesne lands was of little importance by this date. Accordingly, the unity of the shire is most clearly shown by the arrangements for pasture whereby all the township communities of the shire intercommoned during the summer months on a conveniently located waste land or shire-moor. Chat Moss near Manchester can be cited as an example of a small lowland shire-moor, whereas Tynemouth shire-moor was a more characteristic upland waste.

The parallels between this Northumbrian shire system and the social organisation of early Wales, as described in foregoing sections of this paper, are


PLACE NAMES IN CUMBRAN
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PLACE NAMES IN WALAS & TUN
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Fig. 1.—The Distribution of English Place-Names which indicate Brittonic Settlement in Northern England.

immediately apparent. The court adjoining the Welsh *maerdref* may be equated with the North-umbrian *mansio* and a direct equivalent for the appendant bond hamlet of a Welsh neighbourhood can be found in the township of the northern shire. In both areas township communities intercommoned on conveniently situated waste lands in the summer months after May 1 and identities of usage are matched by identities of terminology. In Durham and Lancashire a render of cows, paid on May 1, bore the name *metreth*, of Welsh origin and meaning 'May tribute'. Likewise, a Welsh pasture due, anglicised as *horngeld*, took the name of *cowgeld* in West Yorkshire. That identical renders of the same name should occur in Wales and on the ground of the principality of Elmet seems too close

a coincidence to be explained away by parallel growth alone. As Jolliffe observed, 'Northumbria shows so many parallels to Celtic custom that one is forced to suppose a historical continuity'.

When Jolliffe wrote of continuity, however, he was thinking of a footloose pastoral tradition rather than of permanent Celtic settlement and cultivation. He thus regarded Northumbrian institutions as an amalgam of two civilisations, the one pastoral and the other agricultural. Celtic community, by which he meant solidarity of kinship, united with Anglian lordship to form a distinctive Northumbrian society. To Jolliffe, direct exploitation of the soil in both Northumbria and Wales followed political lordship and thus he regarded cultivation of the demesne land as even more of an innovation in medieval Wales than in Northumbria. But in Wales, as earlier sections of this paper show, permanent settlement, cultivation, and even something closely resembling shire organisation itself appear to date back to a much more remote period.

The shire system survived well into the Middle Ages in Cumberland, Westmorland, Northumberand Durham, but further south it had disintegrated especially after the Norman Conquest. In the central plain of Yorkshire, for example, the system appears to have vanished completely after 1086, though on the flanks of the Pennines clear traces survived into the thirteenth century as far south as Leeds. Nevertheless, if our assumption concerning early permanent settlement on the part of the Celts is valid, then the evidence of place-names indicative of Brittonic survival should, at least in 1086, refer to settlements which formed part of shires or federal manors. This is precisely the case even in south-eastern Northumbria, as the Domesday evidence for Yorkshire makes clear.

In 1086 the discrete manor of Wakefield contained one *caput* of the same name and nine berewicks or appendant settlements. One of these was in the lowlands near Wakefield but the remainder were some 15 to 25 miles further west in the Central Pennines. To this manor of Wakefield there also appertained certain rights of jurisdiction, resembling those typical of shires, which were exercised over appendant sokelands. This soke of Wakefield extended into no less than thirty-eight settlements (Fig. 2). Some of these appendages of Wakefield, like Sowerby in the west, bear Scandinavian names but the majority bear Old English names. To regard them as Old English or Scandinavian creations simply on the basis of this place-name evidence would be rash, for three of them bear names indicating that they had formerly been inhabited by Britons. Bretton, Cumberworth and Walton all indicate a former British population, while Crigglestone, Eccleshill and Dewsbury are names which contain a Brittonic element. Crigglestone refers to a topographic feature and need not imply a settlement, but Eccleshill, derived from the Brittonic *eclesia*, does imply the existence of some sort of British population centre with organised Christian worship, while Dewsbury means the fort of a Welshman named Dewi. These six names, which suggest a Celtic basis for the discrete organisation of Wakefield manor, refer to settlements, all of which were on relatively low land within 15 miles of Wakefield. Equally suitable lowland sites in these areas were unlikely to have been avoided by British settlers, despite the fact that they now bear non-Celtic names. It is improbable, for example, that Normanton, the *tun* of the Norwegians, came into being only in the ninth century. It was probably a pre-existing *tun* taken over by a lesser lord or thegn of Norse origin, who remained subject to the jurisdiction of Wakefield. Similarly, at an earlier stage, the overlord of Wakefield had probably displaced a Celtic lord.

Such displacements were associated with the break-up of the shire, a process still going on in the manor of Wakefield in the eleventh century, so that the status of some appendant settlements was uncertain. There was some doubt, for example, whether Holme in the parish of Almondbury—an outlying portion of demesne—was inland of Wakefield or thegn-land, rather than sokeland. That most of the then surviving berewicks of Wakefield lay in the Pennines is merely a reflection of the needs of seasonal transhumance and indicates the importance of pasture rights in preserving the unity of the Northumbrian shire. The sokelands of Wakefield, representing a more advanced stage of fission, were on the lower lands, while some of the most fertile land within the limits of the Wakefield complex supported independent manors. Dewsbury was at an intermediate stage and, though a separate royal manor in 1066, was described as belonging to Wakefield in 1086.

Similar conditions obtained in other parts of

Yorkshire. For example, Walton in Kirkdale, on the flank of the North York Moors, was a berewick of Kirkby Moorside; similarly the hamlet to the east of Sheffield which is appropriately named Wales, was sokeland of the manor of Laughton-en-le-Morthern, though part of its lands had been converted into an independent manor by 1066. Indeed, of the sixteen place-names in *brettas*, *cumb'an* and *walas* in the whole of Yorkshire ten were recorded in Domesday Book and all save three of these referred to berewicks or sokelands. Even these exceptions can be easily explained. For example Lower Cumberworth was a small manor, on lower more fertile land than the immediately adjoining Upper Cumberworth which remained in the soke of Wakefield. Birkby, near Leeds, was recorded in Domesday Book as a small discrete manor with one berewick, but closer examination of later records reveals that it contained lands appendant to Barwick-*in-Elmet*, which itself was a former berewick of the discrete manor of Kippax and Ledston. Like Saxton-*in-Elmet*, Barwick in 1086 was at an intermediate stage in falling away from its original dependence on Kippax and Ledston, which may well have been the original secular focus of the Celtic principality of Elmet.[7]

Clearly therefore the distribution of discrete estates, as revealed in Domesday Book, merits some consideration as a pointer to conditions of settlement prevailing in earlier centuries (Fig. 3). From the standpoint of physical geography, the most striking feature of the distribution of the capitals or foci of these estates in Yorkshire is their absence from upland areas and correspondingly their concentration into the lowlands, and especially those areas where the juxtaposition of limestone and clay gives rise to fertile intermediate loam soils. Thus, notable concentrations occur along the edges of the Magnesian Limestone outcrop at the foot of the Pennines, and along the scarp edges of the Wolds and the Moors. A surprising number of these settlements are to be found along the banks of the major rivers of the central plain, but areas which remained badly drained until recent centuries stand out as empty tracts; of these, the most

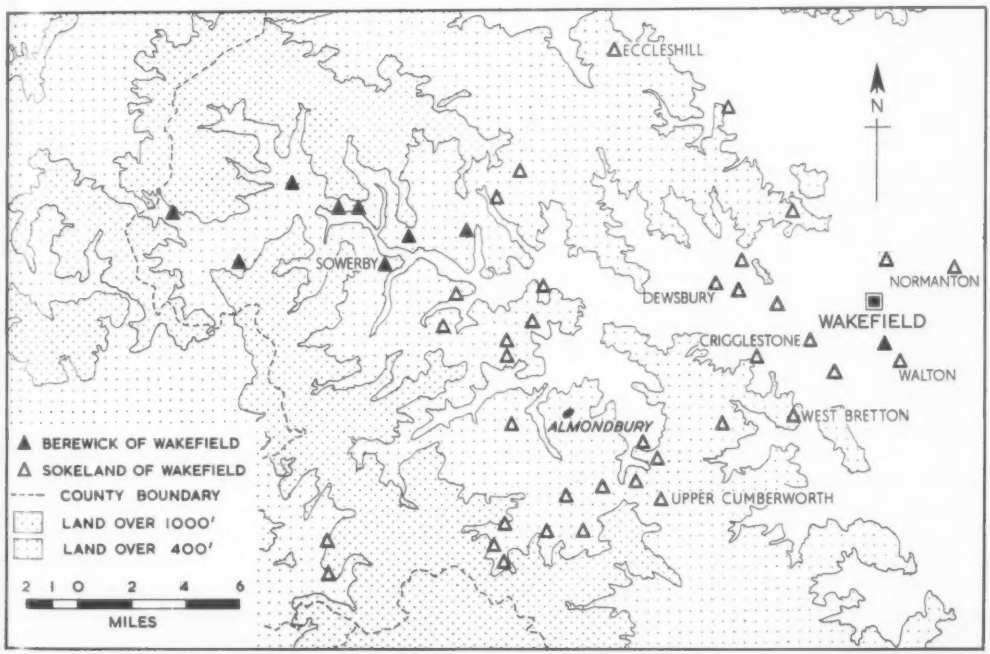
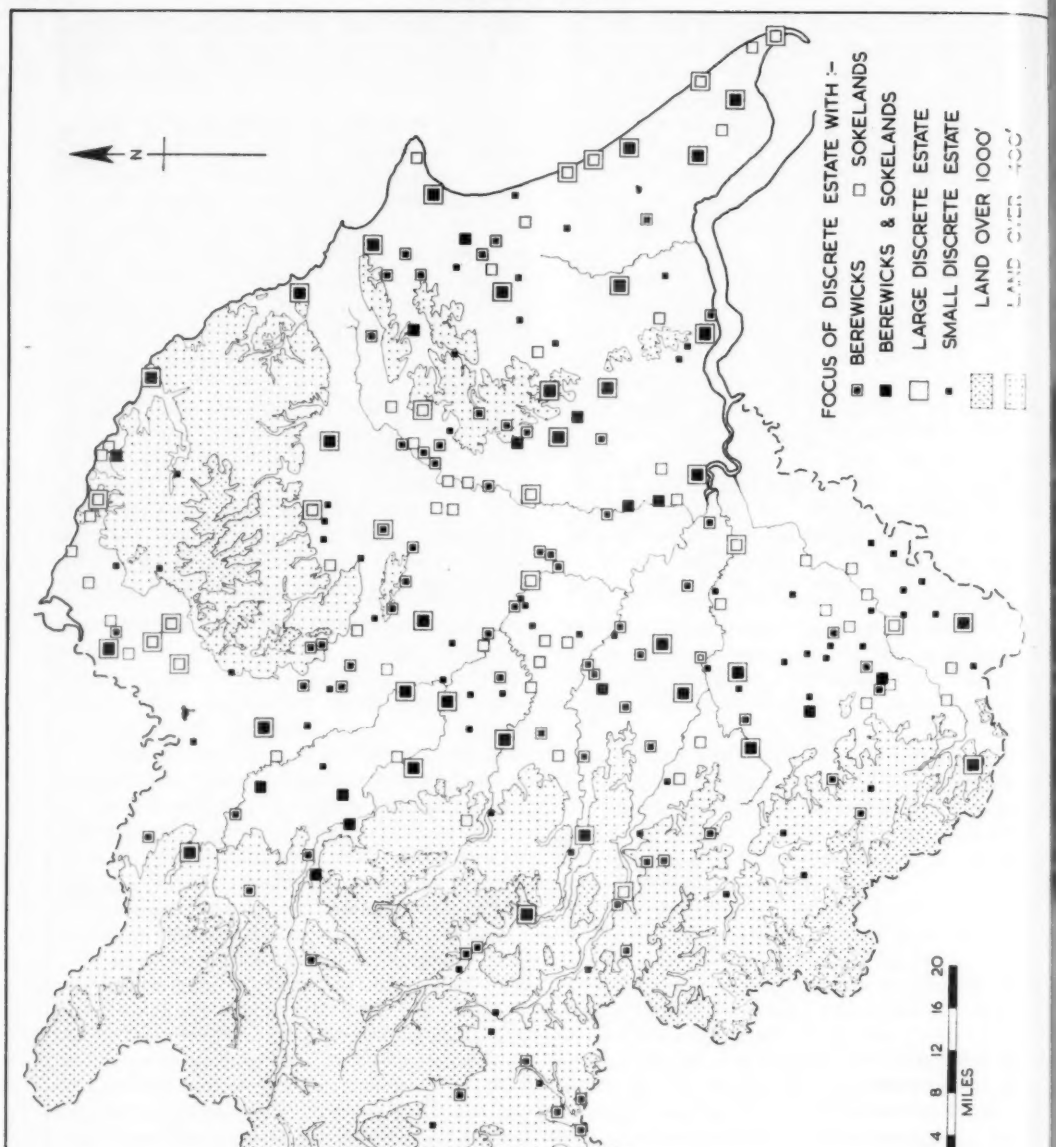


Fig. 2.—The Discrete Estate of Wakefield.


N
FOCUS OF DISCRETE ESTATE WITH :-
BEREWICKS
SOKELANDS
BEREWICKS & SOKELANDS
LARGE DISCRETE ESTATE
SMALL DISCRETE ESTATE
LAND OVER 1000'
4 2 0 4 8 12 16 20
MILES

notable are the Vale of Pickering, the Forest of Galtres north of York, and Hatfield Chase near Humberhead. To the historical geographer, however, the most noteworthy feature is that discrete estates are equally as numerous in areas where Brittonic place-names are not uncommon as in those areas where they are singularly rare. They are, for example, not infrequent along the flanks of the Pennines, yet are hardly less numerous in the valleys which trench the Wolds, an area where but one certain example of a Brittonic place-name has been found. Sites near Driffield, on the edge of the Wolds, and further west near York, were the first to be settled in northern England by immigrant Anglians. That discrete estates in 1086 were equally as numerous in these localities, where Anglian settlement dates back to the fifth century A.D., as they were in territories like Elmet, where Anglians settled centuries later, suggests that this form of territorial organisation was either a very late development or must date from a pre-Anglian period.

The evidence already cited suggests that the latter is almost certainly the case and the same is implied by the archaeological evidence for prehistoric and Roman Yorkshire. On or near the site of almost every Roman settlement in Yorkshire, civil or military, there was a *mansio* or capital of a discrete estate in 1086. A considerable number of the largest and most important discrete estates had their focal settlements on or near Roman roads.[8]

In Wales and along the Welsh border the construction of Iron Age hill-forts appears to have been made possible by that focusing of the resources of a wide area on to a *mansio* which the shire system implies. A similar relationship can be demonstrated for the major hill-fort of Almondbury, in west Yorkshire. As we have seen, the parish of Almondbury contained inland of Wakefield so that, in spite of the distance between Almondbury and the medieval *mansio*, it is possible to equate the construction of the hill-fort with the organisation of the vast Wakefield complex, within which Almondbury was centrally placed. Equally, the shire focused on Hallam, with its sixteen berewicks and inland in Attercliffe and Sheffield, could well have been the territorial base for the fortification of Carl Wark, south-west of Sheffield. Likewise, at the northern edge of the Vale of York the original fortification at Stanwick was probably made possible by the rents and services contributed to the immediately adjacent *mansio* of Aldbrough. Indeed every hill-fort in Yorkshire, including the recently discovered example at Grimthorpe on the Wolds, appears to be within a few miles of the capital of a discrete manor. In the Wolds, however, hill-forts are virtually unknown and the best indices of Iron Age settlement are the chariot burials of a La Tène ruling caste. Appropriately enough, most of these occur near the centres of important discrete estates as for example at Driffield and Hunmanby. It is generally accepted by philologists that the bearers of Iron Age culture in Yorkshire, whether the La Tène warriors of the Wolds or the Hallstatt colonists who first settled near Scarborough in the fifth century B.C., spoke a Celtic language. For this reason, the temporary summer encampment on Castle Hill, which is the earliest Iron Age settlement in northern England, merits close consideration in the present context. Two miles west of Castle Hill, and somewhat nearer the Iron Age rampart on Oliver's Mount, was the *mansio* of the important federal manor of Falsgrave. The one berewick and twenty-five sokelands of this unit are dispersed so as to occupy the more fertile eastern flank of the North York moors, the dip-foot of the Limestone Hills on the northern edge of the marshy Vale of Pickering, and also the slightly elevated morainic bridge which provided the only dry route between the Moors and the Wolds (Fig. 4). Since Iron Age communities peopled both the Limestone Hills and the Wolds, some such disposition would have been strategically advantageous during this remote period. It may well be the case therefore that a territorial entity closely resembling, if not identical with, the discrete manor of medieval Falsgrave was already established in east Yorkshire during the early Iron Age.

Added support for this view is provided by the disposition of linear earthworks to the north and west of Falsgrave so as to contain the dependent hamlets of this federal manor, for these earthworks, interpreted as boundaries rather than military defences, were constructed after the Bronze Age and probably before the coming of the Anglians. Thus the hamlets of Falsgrave, despite their exclusively English or Scandinavian names, could well have been first established by the Celtic communities of the Iron Age known to have

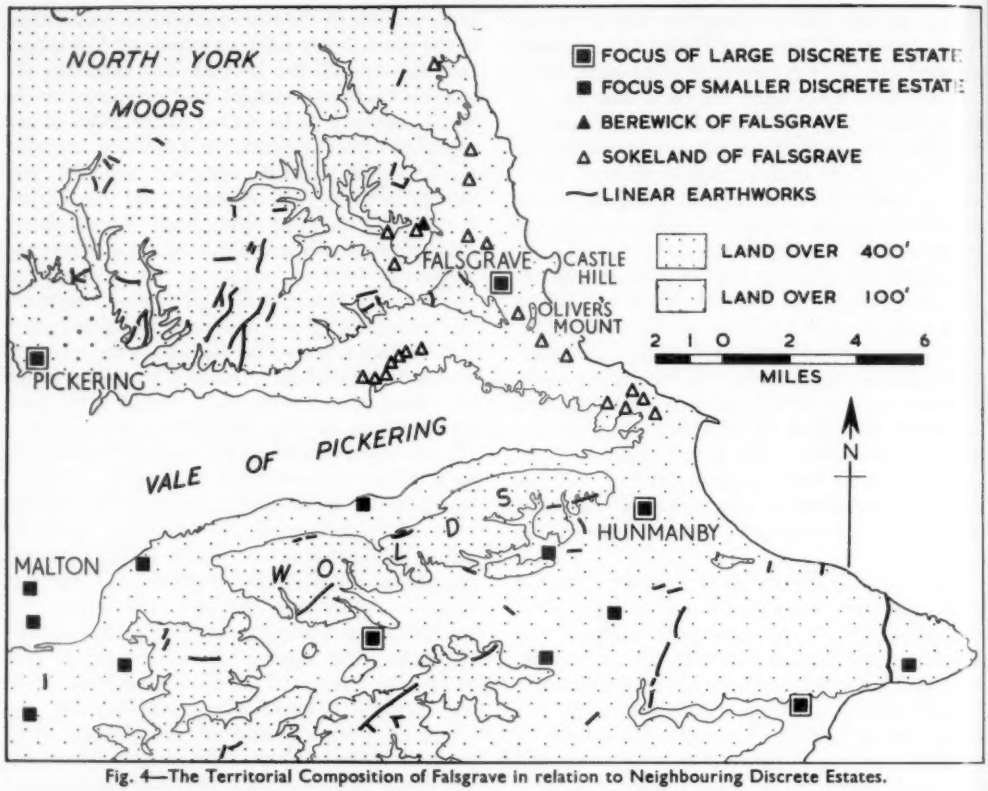


Fig. 4—The Territorial Composition of Falsgrave in relation to Neighbouring Discrete Estates.

occupied this area, and all, save perhaps Newton, were already in being before the Anglians appeared on the scene. That the other discrete estates in the northern Wolds accord closely with the arrangement of similar linear earthworks lends further support to this view.

To no small degree therefore the basic patterns of settlement distribution in northern England appear as a heritage from the period of Celtic occupation. But the most permanent contribution was undoubtedly that of hamlet dwellers, the bond tenants of Celtic overlords, who survived repeated invasions more readily than their masters. Such bond communities, to judge from Welsh evidence, were often of a distinct ethnic stock dating from a pre-Celtic period. For this reason the discrete estate should not be regarded as an exclusively Celtic achievement. It was no more the accomplishment of one ethnic group than was the nucleated village.

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7. The enlargement of former hamlets into villages and the corresponding elaboration of their open fields was one of the major concomitants of the disruption of shires. Thus Barwick-*in-Elmet* emerged in the fourteenth century as a three-field village.
8. Such was Hovingham whose very name suggests early Anglian settlement; here, within the grounds of the manor house, remains of a Roman villa have been found.

NEW BOOKS FOR THE GENERAL READER

The following notes are published by courtesy of the National Book League. They will be reprinted in the next annual supplement to SCIENCE FOR ALL, *an annotated reading list published for the N.B.L. by the Cambridge University Press.*

GENERAL

Woodbury, David O. 1001 QUESTIONS ANSWERED ABOUT THE NEW SCIENCE. *Harrap*, 1961, 15*s*. 313 pp.

A popular general knowledge book, presented in question and answer form, covering space exploration, 'the atomic age', engineering technology, physics, electronics, chemistry, biochemistry and mathematics. Originally published in the U.S.A., this edition has been shortened, and certain alterations made to take account of British conditions. (500)

HISTORY

Crombie, A. C. AUGUSTINE TO GALILEO. 2nd. edn. *Heinemann* 1961, 2 vols., each 15*s*; (*Mercury Books*), paper, each 7*s*. 6*d*.

Vol. 1: 5th–13th century—xviii, 296 pp. 39 plates, line illus. in the text. Vol. 2: 13th–17th century—xvii, 380 pp. 24 plates. (509)

MATHEMATICS

Reid, Constance. INTRODUCTION TO HIGHER MATHEMATICS (for the general reader). *Routledge*, 1960, 12*s*. 6*d*. vii, 184 pp. Diagrams.

A simple exposition of a very complex subject. The 'general reader' for whom it is intended must contribute concentration and an ability to grasp difficult concepts. (510)

PHYSICS

Adler, Irving. TEMPERATURE IN YOUR LIFE. *Dobson*, 1960, 10*s*. 6*d*. 126 pp. Line illus.

This recent addition to a juvenile series is at a rather more advanced level than some of its collaterals, and may be of interest to parents who have missed learning physics, as it certainly will be to their children. (536)

Cohen, I. Bernard. THE BIRTH OF A NEW PHYSICS. *Heinemann* (*Science Study*), 1961, paper, 5*s*. 200 pp. 8 half-tone plates, diagrams.

An account of the revolution in physics during the 16th and 17th centuries. (530)

Einstein, Albert. RELATIVITY: THE SPECIAL AND THE GENERAL THEORY. A popular exposition, trs. by R. W. Lawson. Paperback edn. *Methuen* (*University Paperbacks*), 1960, 7*s*. 6*d*. 165 pp.

Intended for the non-mathematical reader with a background of education to university matriculation standard. Originally published in English in 1920 and in enlarged form in 1954. (530)

Kline, Morris. MATHEMATICS AND THE PHYSICAL WORLD. *Murray*, 1961, 25*s*. ix, 482 pp. Text figures.

With a basic knowledge of school algebra and geometry the reader will get from this book a general view of the role of mathematics in interpreting the physical world, and exploring the universe. The historical background is incorporated. (530)

Landau, L. D., and Rumer, G. B. WHAT IS RELATIVITY? Trs. from Russian by N. Kemmer. *Oliver & Boyd*, 1960, 6*s*. 64 pp. Line illus.

A brilliant simplification by two leading Russian scientists, requiring no technical knowledge beyond arithmetic. Illustrated with humorous cartoons. (530)

Valentine, J. M. TEACH YOURSELF ATOMIC PHYSICS. *E.U.P.*, 1961, 7*s*. 6*d*. 192 pp.

An excellent introduction for the home student, assuming only a background of physics and chemistry to the level already presented in the 'Teach Youself' series But not for 'general' reading. (539)

Van Bergeijk, W. A., Pierce, J. R., and David, E. E., jnr. WAVES AND THE EAR. *Heinemann* (*Science Study*), 1961, paper, 5*s*. 235 pp. 4 half-tone plates, diagrams.

How men and animals hear. Latest findings in acoustics, anatomy, electronics, psychology, hydromechanics, zoology, phonetics and hi-fi engineering briefly discussed by a biologist, a physicist and an engineer working at the Bell Telephone research laboratories. (612)

CHEMISTRY

Holden, Alan, and Singer, Phylis. CRYSTALS AND CRYSTAL GROWING. *Heinemann* (*Science Study*), 1961, paper, 10*s*. 6*d*. 320 pp. 36 pp. half-tone illus. (43 plates plus 3 pp. in colour), diagrams in the text.

The science and art of crystallography, built round the actual growing of twelve types. Very clearly presented, with experiments which will be attractive to the practising amateur. From the U.S.A. (548)

ASTRONOMY

Hoyle, Fred. FRONTIERS OF ASTRONOMY. Paperback edn. *Heinemann* (*Mercury Books*), 1961, 12*s*. 6*d*. xvi, 360 pp. 59 plates, 67 line illus.

A full-scale presentation of current knowledge and theories about the universe, originally published in 1955. The author is Plumian Professor of Astronomy at the University of Cambridge. (523)

Lyttelton, R. A. THE MODERN UNIVERSE. Paperback edn. *Hutchinson* (*Grey Arrows*), 1961, 3*s*. 6*d*. 160 pp. 16 plates, diagrams.

Originally published by *Hodder & Stoughton*, 1956. (523)

Lyttelton, R. A. MAN'S VIEW OF THE UNIVERSE. *Michael Joseph*, 1961, 16*s*. 108 pp. 36 photographs, line drawings in the text.

A crisp outline: the earth, the moon, the planetary and solar systems, the stars and the expanding universe. Shorter and simpler than the same author's THE MODERN UNIVERSE, but requiring close reading. (523)

Moore, Patrick. THE AMATEUR ASTRONOMER. 2nd edn. rev. *Lutterworth Press*, 1961, 25*s*. 317 pp. 16 plates (30 photographs), 61 text figures, 14 star maps, 2 moon maps.

Revised edition of a book first published in 1957. For the serious amateur observer—the beginner as well as the experienced. A straightforward account of basic knowledge is accompanied by advice on equipment and an indication of work within the scope of amateurs. (523)

Toulmin, Stephen, and Goodfield, June. FABRIC OF THE HEAVENS. *Hutchinson* (*The Ancestry of Science*), 1961, 25*s*. 272 pp. 14 plates.

The history of men's conceptions of the universe. This is the first of a series of four volumes sponsored by the Nuffield Foundation Unit for the History of Ideas. (520)

GEOLOGY AND METEOROLOGY

Ager, D. V. INTRODUCING GEOLOGY: THE EARTH'S CRUST CONSIDERED AS HISTORY. *Faber*, 1961, 30*s*. 243 pp. Colour frontis., 19 plates, 58 text figures.

Intended 'to introduce geology to the educated reader'. Dr. Ager is a lecturer at the Imperial College of Science and Technology. He gives a simplified and non-technical account of the evolution of the earth's crust as it developed in the area of the British Isles. Basic principles are introduced as the story unfolds. Despite its title this is a closely written book which may daunt the beginner who, if he is seeking a basic introduction, should turn first to Dr. Harland's book below. (551)

Harland, W. B. THE EARTH: ROCKS, MINERALS AND FOSSILS. *Vista* (*Illustrated Science*), 1961, 25*s*. 255 pp. Tinted drawings and diagrams by Paxton Chadwick.

An attractive introduction to geology, written with the avowed object of arousing amateur interest. Well produced, in large type with good explanatory illustrations. W. B. Harland is University Lecturer in Geology at Cambridge. (551)

Pilkington, Roger. THE WAYS OF THE AIR. *Routledge*, 1961, 14*s*. 186 pp. Line illus. by K. F. Meyer.

A popular narrative account of the nature of the air and its behaviour. (551)

BIOCHEMISTRY

Asimov, Isaac. WELLSPRINGS OF LIFE. *Abelard-Schuman*, 1961, 16*s*. 228 pp.

An informal, easy-reading account of the origin and evolution of life on earth, the development and behaviour of cells and the science of biochemistry. Dr. Asimov (Associate Professor of Biochemistry at Boston University School of Medicine) combines the history of scientific advance with a presentation of contemporary knowledge and theories. (574)

NATURAL HISTORY

Eggeling, W. J. THE ISLE OF MAY: A SCOTTISH NATURE RESERVE. *Oliver & Boyd*, 1960, 30*s*. xv, 280 pp. 20 plates (35 photographs), 5 maps.

A lively and enthusiastic account of all aspects of natural history observation on an island particularly well known for its Bird Observatory. Of interest to botanists and zoologists as well as, especially, to ornithologists. (574)

Goodwin, Derek. INSTRUCTIONS TO YOUNG ORNITHOLOGISTS: II, BIRD BEHAVIOUR. *Museum Press* (*Brompton Library*), 1961, 12*s*. 6*d*. 123 pp. Frontis., 8 pp. plates (15 photographs), 7 text figures.

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Duddington, C. L. INSTRUCTIONS TO YOUNG ZOOLOGISTS. *Museum Press* (*Brompton Library*), 1961, 12*s*. 6*d*. 144 pp. 8 pp. half-tone illus. (24 photographs), 40 text figures.

A very simple introduction to structural characteristics. 'Information for', rather than 'instructions to' readers of 11 up. (590)

Steers, J. A., *ed*. SCOLT HEAD ISLAND. 2nd edn. *Heffer*, 1961, 50*s*. xi, 269 pp. 29 plates, 57 figures including 4 folding maps.

A symposium of detailed studies of all aspects of Scolt Head, off the Norfolk coast—including physiography and evolution, plant ecology, pollen analysis of peats, mosses, lichens and fungi, birds, mammals, marine invertebrates, terrestrial mollusca and insects. This is a scientific work, but will appeal also to amateur naturalists particularly those living in East Anglia. Though this is the 'second edition' of a book first published in 1934, there are nine entirely new chapters and three of the remaining six have been extensively rewritten and enlarged. The plates are all new and include several aerial photographs.

Street, Philip. MAMMALS IN THE BRITISH ISLES. *Hale*, 1961, 21*s*. 185 pp. 32 plates (57 photographs).

A narrative account, for the general reader; includes brief chapters on domestic animals. (599)

TECHNOLOGY

Calder, Ritchie. THE INHERITORS: THE STORY OF MAN AND THE WORLD HE MADE. *Heinemann*, 1961, 25*s*. xxv, 345 pp. 28 photographs, 40 line illus., 11 line maps.

An episodic survey of the effects of advances in technology on world history, from prehistoric times to the present day, the needs and problems of the world today and possibilities of the future. Mr. Calder discusses the lessons of past achievements and failures and the warnings to be found in lost civilisations and man-made deserts, pointing in particular to the dangers of unplanned development. And he describes some of the remarkable experiments now in progress which may lead to greater environmental control in the future. (600)

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Fink, Donald G., and Lutyens, David M. THE PHYSICS OF TELEVISION. *Heinemann* (*Science Study*), 1961, paper, 5*s*. 160 pp. 4 pp. plates, diagrams.

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Hammond, Rolt. BRITISH NUCLEAR POWER STATIONS. *Macdonald*, 1961, 25*s*. v, 182 pp. 18 plates, 15 text figures.

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Reviews

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The book is undoubtedly designed for the large body of persons whom the British Association has been trying to interest in science for many years. It is excellently produced, apart from a few minor misprints, and it is supplied with very many good illustrations and plates; it is a very welcome addition to our literature.

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